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OF THE

SEISMOLOGICAL SOCIETY OF JAPAN.

VOL. V.

1882 MAY—DECEMBER.

TOKIO,
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NOTES ON SECULAR CHANGES OF MAGNETIC DECLINATION IN JAPAN.

BY

DR. EDMUND NAUMANN.

[READ MAY 2ND, 1882.]

It is a well known fact that those phenomena which indicate the magnetic force of the earth are subject to changes which show as a rule a certain regularity by their dependence on periods of time. The magnetic declination varies with the seasons and even every hour at one and the same place; there is also a continual secular change. The hourly oscillations of the magnetic needle are mostly regular, i. e. periodical, and these periods are known to be dependent upon the position of the sun. At night-time the needle is almost stationary, but with sunrise it commences to move, and then continues this motion until about noon, after which it again moves gradually back to the original position. Irregular (non-periodical) movements of the needle may have something to do with earthquakes and volcanic eruptions. Of the secular changes of declination the most complete series of observations has been made at Paris. Here the declination amounted to 8°10′ E. in 1550, then increased to 11°30′, which value was reached in 1580; after this a decrease took place, it became 0° in 1663–1666, turned West and gradually increased in this direction up to the year 1814. At this time it had obtained the value of 22°34′, and now commenced to move back in an easterly direction, but with considerable irregularity. It is, as far as I know, completely unknown to what causes these secular oscillations of the needle can be attributed, mainly because the material at our disposal does not extend over a sufficient length of time to form any valuable judgement upon these difficult questions.

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Therefore I do not hesitate to bring the scanty results of some investigations on the subject before this society, though I must apologize for offering my observations in a very incomplete and rough state. This may perhaps be a good occasion to call the attention and the interest of this society to a subject which must be no doubt of highest importance for seismic science, and I hope that some one who is more conversant with the subject than I may soon show whether there is, or is not, an intimate connection between magnetism and volcanism, and where this connection exists.

Unfortunately the number of magnetic observations in Japan is very limited indeed. It is true that the coast of Japan is pretty well surveyed, and the magnetic variations so important for the mariner are given on published charts, but by a comparative investigation of these data it can be seen that many of the observations appear to be inaccurately determined, if their applicability to scientific purposes is considered, and, on the other hand, these observations are scattered over a large number of years. They are however the only source by which we can construct the present magnetic meridians of Japan. I have tried to make out on the map the courses of the 4° W. and 5° W. meridians. Rough as the curves determined in this way may appear, it can be seen that they follow a crooked line, and that their course appears to conform to certain lines peculiar to the configuration of the Japanese Islands. Materials for constructing even approximately the isoclines and the isodynomical lines are completely wanting, as the magnetometer measurements that have been made only relate to a very small part of Japan. These more scientific determinations were undertaken during the two last years for the geological survey and their results have been published in the *Mittheilungen der Ostasiatischen Gesellschaft.*

In order to compile in the shortest time possible a general topographical and geological map of Japan, and for the purpose of getting the means to provide the surveyors later on with instructions relating to local specialties, I had decided from the very beginning of the geological survey to carry out myself a reconnaissance of the whole country. This

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work I commenced in the beginning of last year, being helped by a few assistants. During 4 months time almost uninterrupted flying surveys had to be made (besides 1 month devoted to the geological Survey of Ani), the total length of the route surveyed by myself being about 400 *ri*. Extensive observations were made both on the geology and on the topography of the country, which entailed an elaborate use of the magnetic compass. Joining the material collected on these excursions together with that represented by the *Chissoku Zenkoku Chiudzu*, made in 1800–1819, and known as Ino's map of Japan, I am enabled to compile a map which will at least correctly show the general features of the country. Mr. Knipping has published in the *Mittheilungen der O. G.* very favorable remarks as to the accuracy of Ino's map, and I took occasion to convince myself that the *Chissoku Zenkoku Chiudzu* is sufficiently correct to be used as a basis for the reconnaissance map of the Geological Survey.

Ino's map contains a great number of compass measurements. These are given in Japanese characters, and the total sum of all the angles laid down in the map in this way amounts to not less than 2040. Comparing the magnetic azimuths as given by Ino with compass measurements of exactly corresponding directions as determind by the Reconnaissance, it can be shown, as I shall endeavour to prove, how much the magnetic declination has changed since Ino. Ino's field books have unfortunately been lost by the burning down of the Uyeno temples in 1868; different essays written by him are likewise no longer in existence, and the map edited in 3 different scales and some record books accompanying this map are all that have been preserved. This map gives a means for the determination of the course of the isogones for the beginning of this century. Possibly the completion of a map, showing the system of the isogones for Ino's time and the accurately determined system of the present isogones, isoclines and isodynamical lines, may in future lead to a better understanding of the causes of the secular oscillations of the needle. I need scarcely point out that continued studies in this direction promise the more, as Japan mainly extends in a North and South direction, and is therefore

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especially fit for magnetic studies; and further, because we have to do with a country which, as history tells us, had periodically a very high volcanic activity; besides Japan might deserve the special and prominent attention of those who are interested in magnetic studies, as it is part of a magnetic island on which the declination is West. The dependence of many of the magnetic phenomena on electric currents moving round the earth may be considered as probable. In consequence we may perhaps expect the existence of a connection between magnetic phenomena and certain internal conditions of the earth, as the earth itself will have its electric currents, and these currents ought to be influenced by internal changes.

In 1870 the *Daigaku* wisely undertook to publish Ino's maps together with his record books, which latter also contain some prefaces and introductions, partly by Ino himself, partly by his colleagues.

Mr. Sekino has, according to my advice, translated the text accompanying the maps, and from his translation I quote the following words of Takahashi Sakuzaemon: "Now the maps have been completed and in place of Ino Tadayoshi, who died before the maps could be published, I myself state the following: The Europeans say that the compass needle generally declines to the West, not pointing due North, and that this variation increases or decreases. Ino Tadayoshi had no better instruments then the common magnetic compass. In Europe these instruments are made with great perfection. Ino, however, did not use any foreign made compass, he on the contrary prepared himself compasses of different kinds. He discovered that the bearings taken with his own compass were always the same, and saw the needle point due North quite constantly, so that anything like the variation of the compass needle was never noticed. From these results he determined that by careful and proper workmanship instruments of the greatest delicacy can be made, and that any piece of iron has much influence upon the needle, deviating it more or less from pointing true North and South. If any one would re-observe the bearings of any places on the map with the common kind of compass, it would most probably give some difference."

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Ino obviously overlooked the magnetic declination, because at his time the meridian of no declination passed through Japan. He was therefore right to a certain degree, except of course in his opinion of the greater perfection of his own instrument. Still one might be astonished that he who was so well versed in determining the latitudes with almost absolute accuracy, neglected those larger declinations which at his time appear to have existed in several parts of the country. The reason of his neglecting the smaller declinations is very easily understood. His compass was, as it appears, too roughly divided, and did not show more than 240 divisions, so that the smallest division of his compass would correspond to $1\frac{1}{2}°$ of the proper division. Besides this, Ino's compass must have possessed a certain error due to the non-congruence of proper and magnetic axes of the needle. It will not be possible to determine the amount of this error, without getting the compass itself. Repeated inquiries about this compass of Ino gave again and again a negative result; still I consider it possible that it has been preserved, and take the liberty of inviting the members of this society to assist in its discovery. The just described error of the compass is a constant one, and cannot therefore influence the general results derived from a comparison between Ino's bearings and the present bearings. Besides the said error, there is still another one, caused by friction. Ino's readings may be considered to have an accuracy of about one degree. This is by no means inconsiderable if Ino's bearings are to be used for the determination of the isogones at his time. But it must be borne in mind that the value of the whole investigation cannot be destroyed by this objection, as this unfavorable circumstance is counterbalanced by a favorable one, namely, by the *great number* of the bearings given in Ino's map. In the Northern part alone, in which I travelled last year, and only for this part did I try to determine the change of magnetic declination, there are not less than about 80. Moreover, a profound study and a careful examination of the map leads to data which do not depend on the bearings given, but on bearings measured in the map, and therefore by carrying the work to the greatest possible extent

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one ought to arrive at a point not very far from the truth.

The methods applied to determine the magnetic variation at Ino's time are as follows.

1. Such bearings of Ino as are given in numbers on his map are compared with bearings measured during the reconnaissance (prismatic compass). The difference between both is determined; the present magnetic variation was taken from charts or approximately ascertained, and subtracted from this difference. + signs have the meaning declinations E., — signs indicate a declination W. This method is illustrated by the accompanying diagram, Fig. 1, of which the following is the explanation.

NS, Astronomical meridian.
P, Mountain sighted.
M, present position of needle.
M_1, position of needle at Ino's time when declination W.
M_2, position of needle at Ino's time when declination E.
Declination at Ino's time $= \alpha - \beta - \varepsilon$ (West) or
$= \alpha - \delta - \varepsilon$ (East).

2. Sightings taken during the reconnaissance have been compared with the directions of the corresponding lines of Ino as determined by measurement on his map.

This method can be applied only in such cases where the station is determined by Ino and the sighting taken not far away from one of Ino's sightings which bears to the same point. From this the declination was determined as before.

3. Some of the more prominent peaks in Ino's map (Taihezan and Ganjusan) are not in the proper position on account of Ino's overlooking the declination of the compass. The proper position of these peaks was determined in Ino's map, and the difference of Ino's given direction from the direction to the newly determined point measured. The value obtained corresponds approximately to the magnetic declination at Ino's time, as illustrated in Fig. 2, explained as follows:—

I, Direction given by Ino.
P, new position of peak.
β, angle given by Ino (small correction applied).

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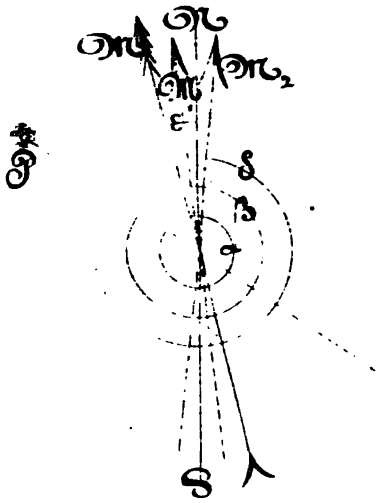

Fig. 1.

Fig. 2.

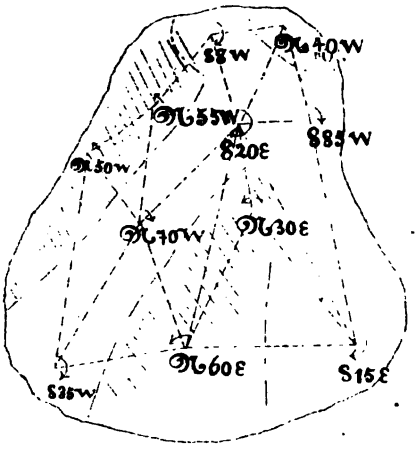

Fig. 3.

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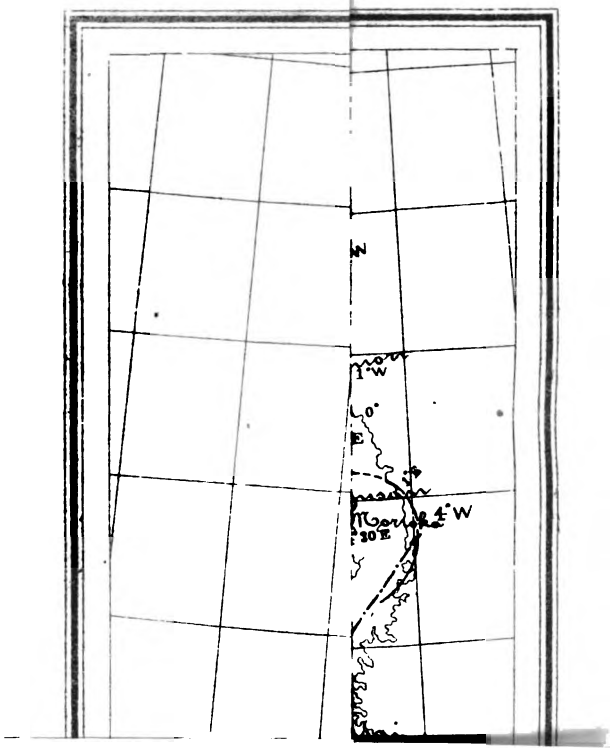

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α, angle measured from map, between newly determined direction and true meridian (true azimuth of direction to peak P, determined approximately by mapping).

D, Direction of magnetic meridian at Ino's time.

$\gamma = \beta - \alpha =$ approximate declination at Ino's time.

5. All those field sketches forming a connection between two stations contained in Ino's map were put together, the straight distance of the stations and the magnetic azimuth of the connecting line were measured, and the results obtained compared with the corresponding lengths and angles in Ino's map. Though the differences of direction procured in this way can not be used for ascertaining the former magnetic variation at the single localities, it is worth notice that the average of the deviation from Ino's directions very nearly corresponds to the probable average increase of the declination since Ino, as derived by application of the methods mentioned before.

Before commencing a discussion of the tables, and of the curves shown on the accompanying map of Japan, I have to remark that the error of the prismatic compass which I made use of, has not yet been determined sufficiently, and that the graphic exhibition of my results can only be taken as a rough sketch.

Most likely it was first at Tokio that Ino was led to the conviction of the great exactitude of his compass on account of its constantly pointing to the true North. For this reason it must be of special interest to measure those directions to distant mountains, which he determined from Tokio. His map contains a great number of red lines diverging from a point at Fukagawa. Mr. Shiraishi selected a point at Fukagawa which must have been very near to Ino's station, if not coinciding with it, and determined the present magnetic azimuths of a number of these directions. All could not be taken, as the weather has been very unfavourable during the last months. The average value of the former declination obtained from these observations is 1° 2′ W. One might have expected a number smaller than this; possibly the just mentioned value will be reduced by subtracting the error of the prismatic compass used. Properly the single values indicating the change of the magnetic

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variation ought to be the same, but every difference obtained from any direction differs from the others. The extreme values are even not less than 2° from each other. This appears to prove that Ino's readings were indeed somewhat roughly taken.

I am able to state however with absolute certainly that the meridian of no declination must have passed through the country at Ino's time. Those old bearings which I tested were taken by Ino during the years 1800 and 1801. Berghaus's *Physikalischer Atlas* contains a map of Erman showing the isogones for the years 1827—1831. Here the 1° W. meridian can be seen to pass through the Eastern part of Yeszo, and to cut off some peninsulas on the Eastern coast of the main island. This gives roughly an average increase of 5° from 1800 to 1881, and of 3° from 1830—1880. According to the values given in charts of one and the same harbor, but relating to different years, we obtain for middle and Northern Japan,

Nanao, 1870—1879 magn. decl. increased from 4° 35′—5° 10′, 35′ in 9 years, or 4′ annually.

Miyadzu, 1867—1879 magn. decl. increased from 4° 30′—5° 15′, 45′ in 12 years, or 3.8′ „

Awomori, 1870—1874 magn. decl. increased from 4°—5° 20′, 1° 20′ in 4 years, or 20′ „

The first two of the values determined very nearly agree with the average annual increase according to Ino's and Erman's observations. On some of the charts the magnetic variation is said to increase about 1′ annually; but this is certainly too little.

While in Northern Japan the magnetic declination certainly increases, it seems according to some charts that it decreases in the South.

If the values for the declinations at Ino's time are put down in a map of Japan and the curves are constructed, the meridian of no declination is seen to pass in a very irregular way through Northern Japan, its longest axis being contained in a median zone of the Island. The West and East declinations are divided left and right of this zero meridian, a result which proves the reliability of the whole process. Strange to say we obtain a very large East declination for Morioka, or the neighbourhood of Ganjusan, and other observations taken in this

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region point out that there was at Ino's time a kind of magnetic island in Northern Japan, with some place near Ganjusan as a centre. A Westerly increase of declination since Ino, amounting to about 19°, is so abnormal that one might rightly expect misreadings or something of that sort to have been committed either by Ino or by myself. But repeatedly examining Ino's plottings I always find

1st, that Ino gives N. 60° W. as the bearing of Ganjusan taken from Uyeda near Morioka.

2nd, that this given bearing agrees with the angle measured in the map.

3rd, that however Ino's position of Ganjusan is certainly wrong, as the mountain is more to the right if seen from Morioka.

4th, that the considerable deviation of Ino's bearing at Uyeda is not the only exception, but that the direction given by Ino for the line Sanbonyanagi Ganjusan (N. 45° W.), does not differ from the corresponding direction measured on the map, but from the newly determined point for Ganjusan (N. 33° 50′ W.) about 11° 10′.

Besides, the declinations for Tokudamura and Minami-hidzume (still more South), the former having 6° 50′, the latter 4° 45′, and lastly Ishiboriza, showing an East decl. of 4°, are all abnormal. These larger East declinations follow each other very regularly, becoming the larger the nearer they come to the place of largest Eastern declination. I can not consider it possible that all these large deviations should be accidental, and I am myself nearly convinced that there has been at Ino's time an irregularity in the isogonic system in the immediate neighbourhood of Ganjusan. Whether this irregularity had any connection with the volcanic seat of the just mentioned volcano, I am of course perfectly unable to say; but certainly the close neighborhood of an abnormal magnetic centre and what may be called an active volcano deserves our attention. According to my knowledge there was no volcanic eruption nor any big earthquake in the regions near Ganjusan at the time of Ino, though a very big subterranean noise was noticed in 1823, which is said to have come either from Ganjusan or from

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another mountain near it.

One might not believe that Ino could overlook deviations of the compass needle amounting to not less than 14° 30°, but it must be borne in mind how persistently Ino held to his idea of the great superiority of his compass. On the other hand, Ino's work had to be carried through against so many difficulties as to make even that error excusable. He states himself that the survey from Noheji to Sendai offered special difficulties on account of the weather having been unceasingly rough and snowy.

To be free from reproach I shall not conceal a few results which do not confirm the just described magnetic irregularity. The difference of Ino's direction Morioka-Hannamaki and that determined by a survey of Mr. Fujitani gives 4° 45′ W. for Ino's time. Further, the examination of Ino's bearings to Hayachine-san from a few stations on the Oshiukaido, under application of method 3, gives 3 west declinations of 2° 15, 2° 30 and 1° 40′. Since not much weight can be given to the angles found by a flying survey, simply because the amount of error depends upon too many varying circumstances, the 3 last values are likewise of inferior importance. The position of Hayachine in Ino's map namely was determined by very acute angles, so that it came by far too much East.

As stated before, the old declination of Tokio was determined to be 1° 2′. The meridian of 1° therefore took its way probably straight across the island approximately in the direction of the astronomical meridian, setting aside the smaller curvatures. Such magnetic curves would have shown quite a different shape at Ino's time from the present.

Before concluding this paper I may be allowed to add an interesting observation which I was fortunate enough to make on the top of Moriyoshisan, an old volcano near the Ani copper-mines, Akitaken. East of the highest point of this mountain lies a small flat covered with dwarf pines and large blocks of lava. At the eastern border of this place I found a block consisting of *exactly the same material* as the surrounding ones, showing very strong magnetism. The block, consisting of granular *Augitetrachyte*, measured about 1.90 met—1.50. By

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none of the blocks in the neighbourhood could any effect upon the needle be observed, while the one in question made it revolve very decidely, so that the needle described an arc of 155° in some cases. Standing upright on the block, I could not observe more than a very slight deviation; but lowering the compass, the needle was seen to move very decidedly. The degree of deviation was found to be very different at different points.

The accompanying sketch, Fig 3, shows the distribution of magnetism. The angles given in the sketch are the bearings taken from the single points to a certain mire whose proper bearing was found to be N. 68 W.

The sketch shows the amount of deviation at different points of the surface and in what direction the needle was turned. The East deviations are divided into two zones which cross each other; on the islands cut out by these zones the deviation is to the W. Fragments broken off had a very distinct polar magnetism. It may be that the magnetism of the block was caused by lightning.

In taking observations with the compass, errors may be experienced by the influence of magnetic masses or blocks. But these accidental sources of magnetism may be easily discovered with even little attention. On the top of volcanic mountains it is always necessary to take the sightings from a number of points. I mention that Mr. Knipping observed a very considerable deviation on the top of Nantaisan. Comparing my bearings taken from the top of Chokai at different points, I found that they differed very considerably.

The above notes do not pretend to be anything more than a kind of programm or introduction for an investigation which will extend over a great number of years. The magnetometer observations of the geological survey will successively be carried out through the whole country, and in the course of the said survey all the bearings laid down in Ino's map will be practically tested in the field. This will lead to the construction of magnetic maps both for the present time and for the beginning of this century.

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DISCUSSION.

Mr. Knipping said: —

With regard to the curves of equal magnetic variation, for the present and for Ino's time (1802-1819) as charted and explained by Dr. Naumann, I am of the opinion, that the observations do not justify some of these curves, at least not throughout their entire length.

The 5° W. curve for the present time follows almost the coastline of Aomori bay in its various bends and different directions; at Niigata it trends out to sea, making a large angle with the previous direction; it encloses Sado island and then returns far into the interior of the main island, forming at Sado an acute angle; from the interior it runs out to sea again off Etchu.

The 4° W. curve of the present time follows the coast line of Kii peninsula at sea in a S.S.W. direction, turns round Oshima, parallel to the coast line, runs up Kii Channel, about N.W., and turns off Awaji to the S. and S.W. again, all within a radius of about 60 to 80 nautical miles.

On no variation chart, based on a sufficient number of observations, have I ever noticed similar irregularities. If account was taken of the probable error in the observations, and of the fact, that in nautical charts, which Dr. Naumann has consulted, the variation is often given at sea in places where no actual observations were taken, solely for the convenience of the mariner in using the chart, and that in many cases the data are approximate only to 20′ or 30′, all these irregularities would disappear.

The line of no variation for Ino's time resembles in the interior, latitude about 37-38° N., an S flattened down considerably in its lower portion; but this extraordinary shape, which one will look for in vain in a reliable variation chart, similarly disappears, if a probable error of 0.5° to 0.7° is allowed for.

In general, curves can only be accepted as fairly representing what they are intended for, when many observations are at our disposal, not only *on* the curves, but also *between* them.

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Whether curves are fair or not, can be further easily tested thus: if two persons, independently, draw by means of the same data the same or nearly the same curves, then the latter may be taken as fairly representing the observations, but in the present instance it is evident, that this test would give unsatisfactory results.

The discovery of Dr. Naumann, that near Morioka in Northern Nippon the variation at Ino's time amounted to 14° E. and decreased gradually to 0° towards the N., W. and S., within a radius of 80 or 100 nautical miles from this point, is highly interesting and important. *A similarly quick change of the magnetic variation, distributed over such an area as the one shown on the chart, is until now only known near the magnetic poles.* It is thus to be hoped, that Dr. Naumann will publish in full all the observations on which his curves of equal variation for Ino's time are based, so as to leave no doubt about the correctness of his results, and also the variation, as found by himself at places near Morioka, because it is highly improbable, that a local magnetic disturbance of such magnitude and extent, as stated for these regions and Ino's time, should have entirely disappeared in 70 or 80 years.

Dr. Naumann replied:—

If Mr. Knipping would take the trouble of re-examining my paper, he would find again and again remarks which point out how little value is attributed by myself to the smaller sinuations of the isogonic lines represented in the map. This map, which I introduced as a "rough sketch" only, is intended to be a mere illustration to my notes. Notwithstanding, Mr. Knipping is attacking in the first line the details of the "sketch"; he even describes the course of the curves very exhaustively and in this way makes up for a deficiency of my paper. I myself have failed to give anything more about the present curves then a short remark about their crooked character, and the "apparent" conformity to the configuration of the Japanese Islands.

Regarding the Sado sinuation of the 5° W. curve, described at length in the foregoing part of the discussion, Mr. Knipping is not aware of the more accurate determinations forming the

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basis of this part. Just for the construction of the said sinuation I was able to make use of about 10 declination values, partly determined by magnetometer measurements, partly established by surveyors of the triangulation of Japan. Those declinations given far out at sea, whose localities could not be fixed approximately, were entirely neglected. I mainly used the special plans and charts of the harbors and bays. For the Idzu curve a greater number of chart declinations and also some magnetometer declinations were employed. That the Sado sinuation was founded on something else than on mariners' observations alone, could be decided without a knowledge of the notes to which the sketch belongs, as the said sinuation goes very far inland. It can be seen from these remarks that Mr. Knipping's assertion: "*all these irregularities* would disappear if account was taken, etc." is *entirely without foundation.* It may be that the special character of many sinuations is incorrect, that this special character will experience substantial changes at a time when a greater number of accurate observations shall be at our disposal, some of the sinuations may even disappear, but certainly not all will vanish.

As far as the irregularities of magnetic lines are concerned, generally these can of course only be shown on maps drawn on a very large scale. Such detailed magnetic maps are still very rare, and consequently very little is known about these irregularities. Magnetic maps on a very small scale, showing for instance the whole surface of the earth do not allow the representation of the special irregularities. Such general maps are a kind of illustration to the theory of Gauss, according to which the magnetic phenomena observed on the surface of the globe are functions of Latitude and Longitude.

The causes of the smaller irregularities consist in conditions of the superficial parts of the earth. The shape of the surface may have some influence, and we may perhaps expect greater complications in the details of magnetic curves where the differences of level are so considerable as on and near Japan.

Lamont's magnetic maps of Bavaria and Southern Germany show the declination lines in intervals from 10′ to 10′.

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Some irregularities may be noticed on these maps. The distance of two declination curves is on an average about 4 German miles; West of Karlsruhe, however, the 1° 40′ and the 2° curve are only 1 mile from each other and near Darmstadt the distance amounts to 8 miles. A similar irregularity may be noticed between Bamberg and Bayreuth, and a still more considerable one in the neighbourhood of Salzburg.

The Bay of Finland gives a further example of exceptional directions of the needle. The irregular distribution of magnetism in this part has been investigated by R. Lenz. He found the irregularity to be greatest on the Island of Stenland. At Junnersö he found not less than 9 poles. It is highly probable that this peculiar irregularity may be caused by masses of iron ore found here at a number of points. These examples prove the existence of irregularities in other parts of the world.

I do not attribute much value to the details of the curves for Ino's time and I have said so in my paper, but I cannot agree with Mr. Knipping if he maintains an error of 0.5 to 0.7° would be sufficient to change the irregular zero curve into a regular one. This change would require a very peculiar and very improbable distribution of the errors. An inspection of the original map will convince Mr. Knipping that the greater number of the data by which the curves were determined are *of course* not on but between the curves. In constructing the map I have endeavoured to draw the curves in exact accordance with the material, however insufficient it may be, I had at my disposal. If two persons (to use Mr. Knipping's example, but not to the same effect), working according to this principle of mine, draw curves, quite independently from each other, but employing the same data, their representations will become nearly the same; but if they do not work according to the same principle, if f. i. one rejects all those observations which make the curves irregular, then one will get a more complicated, the other a less complicated system.

For the construction of the curves relating to Ino's time I made use of about 50 compass measurements. These were taken during the last year on my travels through Northern

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Japan. It must be remarked that my notes apply only to North Japan and that the curves for the present time were put in for comparison.

With regard to Mr. Knipping's final remarks I may be allowed to repeat what I stated in my paper, namely, that my notes are only intented to be an introduction to future studies and investigations, and that I long for the time when it will be possible to publish the magnetic materials to be collected by the geological Survey in a far more complete and definite state than those scanty notes which I took the liberty to bring before this society.

Mr. Knipping replied:—

If Dr. Naumann himself also places little value on the sinuosities of his lines of equal variation, then there was all the more reason to suppress them as much as possible in a *rough sketch*, as those mentioned by me are improbable on the face of them; and a sinuosity, amounting to an acute angle in one line, disappearing entirely in the next one, distant from the first about 100 miles and on the whole parallel to it, can certainly not be called a *small* one, it is rather an *unusually large* one.

That the line near Sado was drawn with the help of values partly determined on shore, of which I am well aware, does not prove anything in favor of this angle, as long as the probable error is not at least roughly given.

The examples adduced from the magnetic survey of Bavaria and Southern Germany, as well as the one in the bay of Finnland, cannot be compared with the irregularities mentioned by me, because they are different in kind. In the first case *varying distances* in a system of isogones, running about *parallel* to each other, have nothing in common with our case, where *the angles or bends* in *one* line, do not appear at all in the *next* one. Secondly, in the Gulf of Finland, the great irregularities are *lasting;* they were observed in 1750, in 1860, and will be there to-day; while the disturbance for Ino's time, marked near Morioka, according to Dr. Naumann's own sketch, has *disappeared entirely.*

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The method employed for drawing curves exactly according to the values found must lead to unsatisfactory results, if the probable error is large in comparison with the quantities determined, as is the case in all three instances which I mentioned.

To Mr. Knipping's renewed objections, Dr. Naumann further replied:—

1. The map accompanying the paper has been designated by myself: "a mere illustration to the notes." Having said in these notes: "the curves follow a crooked line and their course appears to conform to certain lines peculiar to the configuration of the Japanese Islands," it may be easily decided whether it would have been reasonable or not to "suppress" the sinuations. Even a rough sketch of a crooked line cannot look regular. I should consider it a quite unusual method in physical science to reject observations or results at once because they appear "improbable on the face of them." When I was speaking of "the smaller sinuations" I wanted to announce that there are smaller and larger sinuations in the map; the word small can therefore not be taken in an absolute but only in a relative sense.

2. The probable error of a number of values used for the construction of the Sado sinuation does not require special quotation, as it can be determined quite independently from my notes. I have said a number of values found by magnetometer measurement were used. It is generally known to what degree of correctness the declination must be determined with a magnetic theodolite. The maximum of the amplitude of daily oscillation is likewise known. It may be stated however that even an error of 10′ to either side would not be sufficient to make that irregularity which I called the Sado-sinuation disappear.

3. I have not said that the magnetic irregularities in Germany and in the Gulf of Finland ought to be compared with those in Japan. Though detailed magnetic maps are very scarce — those which are known show the existence of irregularities, this is what I pointed out. If it be admitted that the magnetic curves are subject to irregularities in their course,

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it may be expected that these irregularities will be found of a different character and of different extent in different parts of the world.

4. The probable error is not large in all cases, but it is very small in a number of cases. Altogether the map in question does not pretend, standing by itself, to offer final results; it is much more intended to be an inducement to future observations, by which alone the distribution of magnetism in Japan can be shown in an accurate and definite way.

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MONOGRAFÍA GEOLÓGICA

DEL VOLCAN DE ALBAY

ó

EL MÁYON,

ESCRITA POR

ENRIQUE ABELLA Y CASARIEGO

Ingeniero Jefe del Cuerpo de Ingenieros de Minas, Jefe de Admon. Civil de 2.ª clase, Comendador de número de la Real y distinguida órden de Isabel la Católica

è individuo de la Sociedad Seismológica del Japon.

(Publicado por la misma.)

C

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Á LA SOCIEDAD SEISMOLÓGICA DEL JAPON.

Forman uno de los objetos de esta Sociedad, á la cual me honro en pertenecer, los estudios que se refieran á fenómenos volcánicos. No es extraño, pués, que autorizado por un acuerdo del Gobierno Gral. de estas islas, le dedique este pequeño trabajo, que he tenide ocasion de hacer, sobre el mas importante de los volcanes activos de la isla de Luzon, el gran Máyon de la provincia de Albay.

Enrique Abella
y Casariego.

Manila, Abril 1° de 1882.

Read May 30th, 1882.

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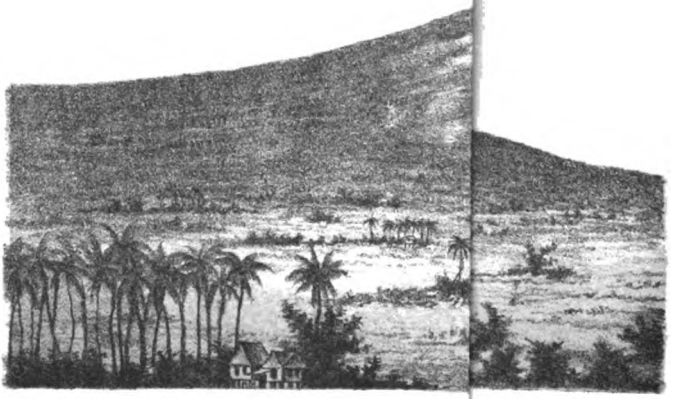

1. Cerro Linyion

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EL MÁYON.

En el estremo S. E. de la isla de Luzon, se alza aislado y magestuoso, el monte volcánico Máyon, en forma de inmensa tienda de campaña cónica, teñida de un color gris violáceo con manchas blanquizcas y surcada por multitud de barrancos negros y rectilíneos que se retuercen en curvas mas ó menos marcadas al acercarse á la emboscada base de la montaña, que se presenta, además, coronada de un inmenso y prolongado penacho blanco que, á manera de enorme catavientos, se estiende y abate impulsado por las fuertes corrientes de aire que suelen reinar à la altura de 2.734^{m} que su cúspide alcanza[1].

De noche, el espectáculo con la erupcion actual, es mas hermoso todavia. Desde Albay, Legaspi ó Daraga, la silueta inmensa del monte se destaca en negro, sobre un fondo azul oscuro salpicado de estrellas, cuyo centelleo apénas se distingue, al rojo y vivísimo resplandor de las lavas incandescentes que magestuosamente asoman á través de las enormes grietas superiores del cono, que parece entreabrirse descubriendo su interior ardiente como el de un alto horno. Las lavas descienden apelmazadas y perdiendo brillo hasta que, decrepitando y subdividiéndose al chocar entre sí ó con las aristas y salientes de la ladera, vuelven à encenderse con mas fuerza y deslumbramiento, asemejándose entónces á una soberbia cascada de fuego que se pierde en las laderas inferiores; oscureciéndose luego el monte durante algunos segundos ó minutos, para volver à iluminarse de nuevo, cuando la lava alcanza otra vez los puntos de salida.

Esta hermosa montaña es muy conocida en Filipinas por su magnitud, por la regularidad de su forma y por la triste celebridad de los estragos que, en sus erupciones mas fuertes, ha

(1) Segun Jagor y segun la carta de la Com. Hidrogr. de marina 2522^{m}.

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causado y causa todavia á las numerosas y ricas poblaciones que se extienden alrededor de su base; apesar de lo cual, apénas puede conocerse la verdadera historia de las mas importantes fases de su actividad volcánica, porque no existen noticias anteriores á la conquista del Archipiélago, y las posteriores solo se refieren á las mas grandes catástrofes ocurridas.

Erupciones.

Segun los datos que hemos podido consultar sobre este interesante asunto; la erupcion del Máyon mas antiguamente conocida, se refiere al año 1716, sin que se tengan detalles sobre su entidad; pero el dia 20 de Julio de 1766 se cita otra, al parecer mas considerable ó tal vez mas detalladamente descrita, en la que apareció la cúspide del cono completamente incandecente, viéndose descender hácia el oriente una gran corriente de lava durante 6 dias consecutivos.

Tambien se cita la fecha del 23 de Oct° del mismo año como la de otra *erupcion horrorosa*[1] que en pocas horas asoló el pueblo de Malínao y causó grandes estragos en los de Albay, Cagsáua, Camálig, Budiao, Guinobátan y Ligao; pero este desastre debe en nuestro concepto atribuirse, no á los fuegos subterráneos del Mayon, sino à la gran cantidad de materiales incoherentes que sus laderas contienen, los cuales fueron arrastrados à las llanuras de los pueblos inmediatos, y con gran violencia, por una de esas terribles tempestades giratorias que en el pais se llaman *báguios*. En las descripciones de aquella época se lee, en efecto, que, al mismo tiempo de la *erupcion horrorosa*, se manifestaba una fuerte tempestad por el O. N. O. *que roló* al Sur, expeliendo el volcan *tal cantidad de agua* que entre Líbog y Albay, corrieron rios de mas de 30 varas de ancho y, hácia el S. O., quedaron los cocoteros y otros árboles sepultados hasta sus copas.

En el año 1800 tambien se cita otra considerable erupción que causó así mismo bastantes desgracias; pero la que se manifestò el 1.° de Feb.° de 1814, es la que ha dejado mas profundos y dolorosos recuerdos, por la imponente magnitud del

(1) Estado geográfico de los PP. Franciscanos.

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fenómeno y los estragos que causó. El Párroco entónces del pueblo de Guinobátan, testigo presencial de aquella catástrofe, la refiere en estos términos[1]: "Precedieron, la noche ántes, "repetidos temblores; siguieron por la mañana del dia 1.° con "un fuerte sacudimiento á lo último, è instantáneamente arrojó "por su boca como una nube que subia piramidal y formaba la "figura de un penacho muy vistoso[2]. Como el sol estaba claro, "presentaba diversas vistas el fenómeno asolador. El pico negro "iba hácia arriba en sombrío, su medio en varios colores y su "estremo estaba de color ceniciento. Mas á poco de estar "observando este objeto, se sintió un gran terremoto seguido "de fuertes truenos. Seguia asi arrojando lava[3] con violen- "cia, cuando á poco se extendió la nube que formaba: oscureció "la tierra, incendió la atmósfera, y de la tierra se veian salir "rayos y centellas que se cruzaban unos con otros, formando "una tempestad horrososa. A esto se siguió instantáneamente "una lluvia tan terrible de gruesas piedras encendidas y "calcinadas[4] que arruinaban y quemaban cuanto encontraban. "Poco despues piedras mas chicas, arena y ceniza; durando esto "mas de tres horas y la oscuridad como cinco. Abrasó y "arruinó enteramente los pueblos de Camálig, Cagsáua y Budiao "con la mitad de Albay, lo mismo el de Guinobátan y ménos "el de Bulusau por no correr hácia estas partes tanto la erup- "cion, y porque el viento le dió la direccion al S. La oscuridad "llegó à partes bastante distantes como à Manila è Ylocos, "pasando la ceniza, como aseguran algunos, hasta China, y los "truenos se oyeron en muchas partes del archipiélago"[5].

Humeando mas ó menos, permaneció tranquilo el Mayon, terminada esa erupcion, hasta el año de 1827, en que comenzó

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(1) Estado geográfico etc. de los PP. Franciscans, pàgina 255.

(2) El llamado *pino* volcánico que caracteriza el comienzo de la fase *explosiva* ò pliniana.

(3) Nótese que se llama *lava* la nubè de vapores y cenizas que formaban el *pino volcánico*.

(4) *Bombas volcánicas* que se ven hoy en las llanuras del S. y del S. O. del volcan y que por su gran tamaño y aristas vivas, debe suponerse que no fueron transportadas por las aguas. Tambien existen en la isla de San Miguel, al E. de Tabaco.

(5) En estas apreciaciones es posible que haya alguna exageracion, porque, reinando entónces la monzon del N. E., las cenizas no pudieron pasar por Manila y llegar á China.

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á manifestarse otra no tan ruidosa, que duró hasta principios del año siguiente.

En 1834 se manifestaron corrientes de lava incandescente que, desde la cúspide, bajaba en todos sentidos á lo largo de los barrancos superiores; permaneciendo en este estado, con períodos de aumento ó disminucion, hasta el mes de Mayo del año siguiente, en que durante algunas horas se vió una erupcion de piedras y cenizas lanzadas solo à pequeña distancia de la cumbre, oyéndose al mismo tiempo un ruido semejante al de un fuerte trueno.

El 21 de Enero de 1845 se oyó nuevamente un ruido fuerte subterráneo, manifestándose una erupcion de unos diez minutos, que se repitió un cuarto de hora y una hora despues, apareciendo luégo una nube de cenizas que cayeron sobre Camàlig y Guinobátan á donde el N. E. las impulsaba. Se oyeron durante algun tiempo ruidos subterráneos, que de dia, se asemejaban al de multitud de piedras que chocasen entre sí, y de noche, al de una lejana cascada. Estos fenómenos fueron debilitándose poco à poco hasta terminar por completo al cabo de una semana, sin que en esta erupcion hubiese que lamentar ninguna desgracia personal.

En el año siguiente de 1846 ocurrió tambien otra erupcion, y en el de 1851 se observaron otras dos insignificantes de cenizas.

El 13 de Julio de 1853 se anunció una gran erupción con ruidos considerables subterráneos, pero sin terremotos; manifestándose en efecto à medio dia una alta columna de ceniza en forma de árbol; viéndose rodar al mismo tiempo, hasta el pié de la montaña, piedras incandescentes que destruyeron muchas casas, produciendo la muerte de 33 personas. Quedaron, todos los pueblos de la base del volcan, recubiertos de una capa de ceniza, apesar de que el fenómeno duró solo hasta la tarde.

En todo el año de 1858 se manifestó casi sin interrupcion una suave deyeccion de lavas que, en las noches claras, se veian correr incandescentes por las vertientes de la montaña.

En las noches despejadas de los años sucesivos, se observaba á veces cierto resplandor en la cumbre; pero no volvió á manifestarse una verdadera erupcion, hasta el 8 de Dic° de 1871. Amaneció el dia percibiéndose algunos ruidos subter-

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ráneos, y habiéndose oido tres muy fuertes entre siete y ocho, se vió en la cúspide del volcan una gruesa columna de humo que, elevándose magestuosamente á bastante altura, fué esparciéndose y descendiendo lentamente; notándose en seguida la salida de cenizas, arena y lavas, arrojadas con poca violencia, é impulsadas las primeras por el viento N. E. hacia Camàlig y Guinobàtan, en cuyos pueblos tenian que andar con luces, huyendo muchos habitantes hácia los cerros del O: tal era la cantidad de cenizas que caian, y entre ellas algunas pelotillas de lodo del tamaño de balas de fusil y mas pequeñas. A las diez, comenzó á despejarse, dejando sobre los campos y tejados una capa de ceniza que tendria un espesor de 4.mm A la una de la tarde, recrudeció la erupcion con fuertes detonaciones y relámpagos, y por la noche pudo ya verse el monte iluminado por los surcos de lava que descendian hácia la parte de Albay y Legaspi, arrollando toda la vegetacion recrecida en los 12 años de calma que se habian esperimentado. Las aguas de los rios de Camàlig y Guinobàtan y el Quinali, se tiñeron de un color plomizo semejante al de las cenizas que llevaban en suspension. En la visita de Bocton hubo dos personas asfixiadas, y una quemada en la de Buyuan.

El 31 de Octe de 1875, que algunos citan tambien como fecha de otra erupcion, solo se experimentaron, segun todas las apariencias, los efectos de un fuerte báguio sobre el inmenso condensador, compuesto de materiales incoherentes, del cono volcánico. Causó sin embargo 1500 víctimas y enormes destrozos materiales, mayores que los de las erupciones volcánicas conocidas. El Sr. Drasche refiere este hecho como un ejemplo de lo difícil que es conocer bien ciertos hechos, aún en los puntos mas cercanos de donde ocurren, puesto que, segun dice, se atribuyeron en Manila à los fuegos del volcan el desastre de 1875; y efectivamente, aún en el mismo Albay, no faltaron personas que nos aseguraron que el volcan tuvo una verdadera erupcion, al mismo tiempo que el temporal.

Diez años permaneció el Máyon tranquilo y silencioso, hasta que, en la noche del 6 de Julio de 1881, apercibieron los habitantes de Tabaco, apesar de la lluvia que caia à torrentes, un resplandor vivísimo hácia la cumbre del monte, que solo

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podia provenir de la aparicion ó próxima salida de las lavas incandescentes; y en efecto, en la noche del 16 de Julio, los pueblos del S. y del S. O. del volcan, vieron descender las lavas enrojecidas, por la gran barranca formada en el báguio de Oct° de 1875; repitiéndose el espectáculo á las once de la noche del dia 22, aunque ya entonces le acompañaba un ruido semejante al de un lejano ronquido.

Desde entonces la erupcion ha continuado y continúa todavia con los períodos de incremento ò decrecimiento consiguientes, creyendo algunos haber observado que en los plenilunios las deyecciones eran mas abundantes y visibles.

Sin que esta tranquila actividad cesara, el dia 21 de Nov°, á las once y media de la mañana, la cúspide del Mayon comenzó á despedir abundantes y espesos vapores grises, muy diferentes á los que ordináriamente emite para formar su gran penacho, los cuales parecian condensarse y descender lentamente; observándose al mismo tiempo un incremento en la salida de las lavas, apesar de ser de dia, revelado por los visibles regueros de gases y humo blanco que se elevaban de los barrancos. Poco despues de las doce, se percibió un ruido sordo; y á las dos de la tarde, los vapores grises que rodeaban el volcan, eran considerables; y en todos los pueblos del S. y S.O. se notaba la atmósfera muy túrbia, pesada, y excesivamente calorosa. Comenzó entonces á levantarse el viento del E., y la mayor parte de estas nubes de ceniza, fueron impulsadas, como casi siempre sucede, hácia los pueblos de Camálig y Guinobátan. El 14 de Dic° volvió á repetirse este fenómeno aunque en mucha menor escala.

Los caracteres principales y exteriores de esta erupcion son, pues, tranquila deyeccion de lavas á traves de varias bocas volcánicas que forman las hendiduras y rajas superiores del cono, en su parte S. y S.S.E.; salida de éstas en estado casi sólido, fragmenticio é incoherente, aunque siempre incandescentes; incrementos y decrecemientos irregulares, ó á lo menos poco estudiados, en la actividad de esta erupcion; y percepcion, durante algunas noches, de ruidos subterráneos muy lejanos, generalmente precursores de mayor abundancia en la deyeccion de la lava.

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En cuanto á movimientos seísmicos, para observarlos, llevábamos á Albay, y montamos en la Casa Gobierno, dos sencillos seismómetros, uno de péndulo para los movimientos de oscilacion y otro de resorte para los susultorios ó de trepidacion[1]. En una semana de observacion, el de péndulo permaneció perfectamente tranquilo, pero el de movimientos verticales nos acusaba diariamente un movimiento de 2 à 3 milímetros que, sin embargo, no era sensible á los sentidos.

El carácter fragmenticio é incoherente de las lavas modernas del Mayon ha inducido al distinguido geólogo austriaco Drasche[2] à compararlos con los detrítus de los volcanes de la isla de Java, estudiados por Junghuhn, estableciendo ademas, como otro carácter distintivo de las erupciones de este volcan, (que le sirve para clasificar su estado actual de actividad interna,) el hecho de que solo arroja *grandes cantidades de cenizas y, alguna rara vez, escasas masas de lava, que parten siempre de la cumbre del monte*[3]. Sin embargo, ni la descripcion de las erupciones conocidas del Mayon, que hemos estractado detalladamente con este objeto de documentos ó noticias verídicas, ni la observacion de la que actualmente se está verificando, permiten atribuirle semejante propiedad ó carácter. Las erupciones conocidas y la que personalmente hemos observado algunos dias del mes de Dic^e^ y Enero, se verifican, por el contrario, arrojando, como elemento puramente *eventual y aleatorio, pequeñas cantidades de ceniza, generalmente al comienzo* de la erupcion ó de los períodos en que redobla su actividad; vertiendo en cambio durante muchos dias ó muchos meses *gran cantidad de lavas* enrojecidas que, aunque fragmenticias é incoherentes, fluyen de una manera casi contínua, no solo de la cumbre del monte, sino de las numerosas hendiduras *ó bocas subordinadas* abiertas

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(1) El de péndulo lo debemos à la complacencia del P. Faura, pues los que han de servir para los estúdios de la Inspeccion, todavia no han llegado de Europa y del Japon. El de resorte, fué construido por nosotros mismos, y estaba constituido por una espiral cargada de un peso y un índice que sumergiéndose en un líquido coloreado acusaba los movimientos verticales.

(2) Datos para un estúdio geologico de la isla de Luzon. Bol. de la Com. del Mapa Geol. de España, tomo 8°.

(3) Datos etc. Bol. etc. pag^a^ 338.

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hoy hácia el S. y S.S.E. de las vertientes, algunas de ellas *muy bajas*, casi en la mitad de la altura del cono.

En nuestro concepto, tanto la misma abundancia de los puntos de salida de la lava, que la hace repartir sobre una gran superficie de las laderas, como el estado incoherente de ella, que facilita su transporte y arrastre, favorecido ademas por la empinada pendiente del cono, hacen que no puedan conservarse los conos parásitos, accesorios ó subordinados que equivocadamente echa de menos Drasche en la mayor parte de los volcanes de la isla de Luzon[1]

Veamos ahora la constitucion hidrográfica y orográfica del Máyon.

HIDROGRAFIA.

La region orográfica de este monte está limitada principalmente por los rios Quinali de Tabaco, ó del N., Quinali de Ligao ó del S., el Paùlug y el Yána. Los mas importantes por su caudal y por las regiones orográficas que entre sí separan son los dos Quinalis.

El primero nace, entre Guinobàtan y Camàlig, de varios arroyuelos que unos vienen de las faldas del Máyon, en direccion N. à S., y otros de la falda occidental del monte Quiluinan, en direccion contraria; corriendo luego al O. N. O., y desaguando en la laguna de Bato de la provincia de Camarines Sur, con caudal y cauce ya suficientes para permitir la navegacion en bancas desde Polangui. La comarca que baña este rio se llama partido de la Yraya, que ha sido por cierto generalmente el mas castigado por las erupciones del volcan.

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(1) En efecto, de los volcanes que hemos tenido hasta ahora ocasion de ver, aunque no de estudiar todavia, podemos citar en 1er término el gran Banàjao que, hacia la parte de Lucban, tiene el cono subordinado llamado el Banajillo, y tal vez por un estudio detenido pueda tambien considerársele subordinado el S. Cristóbal; el Maquiling que tambien los tiene hacia el barrio Biting de Bay y hacia los Baños; las numerosas bocas volcánicas que existen entre el S. Cristóbal y el Maquiling, en la comarca de Yum Calanan y S. Pablo; y probablemente tambien en otros muchos volcanes que han sido muy poco estudiados hasta ahora; pero de todas maneras, los ejemplos citados prueban que el hecho no es tan generalmente característico de Luzon como supone Drasche, y esto confirma, una vez, mas lo espuesto de ciertas generalizaciones teóricas sobre paises poco conocidos y materias tan delicadas.

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El Quinali de Tabaco, al N., y el Paùlug, al S., corren en opuestas direcciones, formando una estrecha garganta que separa las masas montañosas del Mayon y el Masaraga, y por ella sigue el camino de herradura que une entre sí los pueblos de Tabaco y de Ligao.

El primero de esos rios, tiene su fuente principal en una pequeña laguna del Masaraga, y, bajando hacia el N E., desemboca en el mar, muy cerca del pueblo de Malínao, con un cauce y un caudal de aguas tambien muy considerable, pues recoge gran parte de las de la falda N. del Máyon y casi todas las de la parte oriental del Masaraga.

Muy cerca de la importante visita de S. Antonio, en un barrio que se llama Tancalao, existe una fuente ferruginosa que ha adquirido cierta nombradía por haber producido sus aguas, usadas en bebida, algunas curas en ciertas enfermedades. Brota en la ladera izquierda del rio, frente á un mogote volcánico situado en la opuesta márgen, y sus aguas, de un marcadísimo sabor estíptico antes de mezclarse con las del rio, dejan sobre la dolerita un considerable manchon de óxido férrico hidratado. Esta dolerita, en las cercanias del manantial, se presenta algo descompuesta, tanto por los efectos metamórficos actuales, de las aguas ferruginosas que la penetran en varios puntos, impregnándola fuertemente de óxido férrico; como probablemente tambien, por la accion que han debido producir sobre ella las rocas volcánicas y vítreas del mogote Tancalao.

En este punto se observa un curioso cambio de direccion del rio, producido probablemente por alguna de las erupciones del Máyon. Al salir del barrio S. Antonio, para ir à Tancalao, hay una bajada, formada por un cantil que, casi limitado hoy en aquella parte por el arroyo que baja de Buhían, se dirige al O. S. O., por el Bantayan, y se reune por fin al cantil que forma allí la márgen derecha del rio Quinali. Este cantil señala indudablemente la antigua márgen del rio, que dejaba, pues, á la izquierda el cerrillo Tancalao que pertenece, por lo tanto, á la region orográfica del Masaraga, aunque hoy parezca pertenecer à la del Máyon. Esto no quiere decir, sin embargo, que no pueda haber provenido de alguna boca subordinada á este último volcan.

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El rio Paúlug es de menos importancia que el que acabamos de considerar, y corre en direccion N. E. à S. O. Nace en la misma garganta por donde pasa el camino de Ligao y Tabaco, y desemboca en el Quinali del S.

Por último, el rio Yána está formado por la reunion de dos arroyos que bajan respectivamente del Máyon y de los montes Quituinan y Oag, en direcciones opuestas de N. y S., corriendo hácia levante, luégo que se reunen cerca de Malápod, para formar el Yána, entre el cerro Lingion y el Máyon, desembocando al N. de Legaspi en el seno de Albay.

Uno de sus afluentes, el llamado arroyo Busay, presenta cerca del puente de la calzada de Daraga á Camàlig una hermosa cascada de poca altura, pero de abundante caudal de agua. El otro, que baja del Mayon y que pasa muy cerca de las ruinas del destruido y no reedificado pueblo de Budiao, recoje las aguas de un abundante manantial sulfuroso, ligeramente termal, que posee, segun se asegura, propiedades medicinales. Analizadas en 1850 estas aguas, por D. E. Robertus, dieron el siguiente resultado:[1]

Cloruro de sodio	0'579.
Sulfato de cal	0'403.
Carbonato de cal	0'314.
Hidrógeno sulfurado	0'283.
Agua	998'421.
	1000'000.

Además de estas corrientes, que limitan el macizo montañoso del Máyon, existen una multitud de barrancos y arroyos radiales, casi rectilíneos cerca de la cúspide, dada la regularidad de la forma cónica del monte; que mas abajo se recurvan para desembocar en las citadas corrientes principales ó en la mar. Entre ellos los mas notables son el Bulauan, el Parel, el Cagbájai y el Bigá que desembocan en los senos de Tabaco ó de Albay.

Orografia.

La orografia del Máyon tomada en conjunto, es bastante sencilla, puesto que su forma cónica, que hemos comparado à la

(1) Estado geográfico etc. pag.ª 272.

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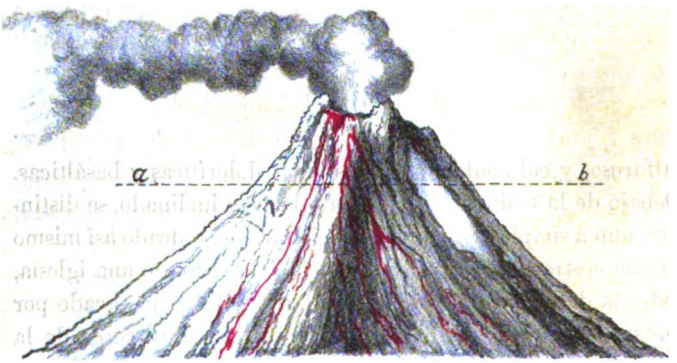
3.



LOS PUNTOS Y TRAZOS ROJOS REPRESENTAN LAS LAVAS INCANDESCENTES.

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de una inmensa tienda de campaña, sorprende por su regularidad y aislamiento. Sin embargo, observado con detencion, presenta algunas pequeñas irregularidades orográficas á él subordinadas, como son las colinas comprendidas entre los rios Bulauan y Dugàs y los cerros aislados de Tancalao, al N., y Lingion, al S.

La parte superior del cono, mirada à simple vista, termina casi en punta; pero observada con alguna detencion, y sobre todo con un buen anteojo desde Legaspi, Albay ó Daraga, se ve un pequeño truncamiento en forma de media luna, con dos eminencias; de las qué la del O. (izquierda del dibujo 3) es la mas alta, constituida por un potente lastron inclinado, cuyo asiento despide vapores blancos. Hácia el E., (parte de la montaña que mira á Líbog) se ve asomar un cono rudimentario que humea, detrás del encostrado blanco que por aquella parte se ve, producido probablemente por la kaolinizacion de los feldespatos y produccion de sulfato de cal á favor de los vapores sulfurosos y cal contenida en las lavas doleríticas y basálticas. Debajo de la eminencia mas alta ó lastron inclinado, se distingue, aun á simple vista, un enorme pilar que, rodeado así mismo de una costra blanquizca, se asemeja á la torre de una iglesia, rodeada de blanco caserio. Este pilar, en el dibujo sacado por Drasche en Abril de 1876, lo representa[1] muy cerca de la cumbre, lo cual parece indicar que desde el principio de la actual erupcion, comenzada, como hemos visto, en Júlio del año anterior de 1881, el cono ha aumentado en altura toda la parte superior à la linea *a b* de nuestro dibujo; cuyo hecho no es inverosímil, aunque parece que debiera haber ido acompañado de cierta fuerza eruptiva, que no parecen haber observado los habitantes de los pueblos de la falda.

Las colinas del N. E., que dominan al pueblo de Malilípod presentan dos ó tres cumbres en série lineal, de formas cupuloides que lo mismo pueden atribuirse á conos parásitos, modificados por las erosiones considerables del Máyon, que á una ó varias potentes corrientes de lava que se hubieran insinuado en aquel sentido; semejantemente á lo que Drasche supone en las

(1) Bol. de la Com^n del Mapa Geol. de España. Tomo 8.°, cuad^o 2.°, pag^a 337 (69).

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colinas que se encuentran al O. de los volcanes apagados Yriga y Malínao.

El cerro Tancalao, situado al S.O. de la visita de San Antonio jurisdiccion del pueblo de Tabaco, dijimos ya que presenta la forma de un mogote, aislado entre el caúce actual y el antiguo del rio Quinali del N., formando hácia este último, un tajo vertical ó acantilado, al pié del cual pasa el camino de Tabaco á Ligao.

De forma análoga, aunque de masa un poco mas considerable, se presenta el cerro Lingion al N. de Albay y Daraga, al pié del Mayon y á él subordinado; sin que pueda explicarse su formacion, lo mismo que la del Tancalao, mas que suponiendolos restos de conos volcánicos subordinados, pues las acciones atmosféricas de por sí solas, áun actuando sobre los materiales sueltos, que Drasche supone que componen la totalidad de esta colina, difícilmente llegarian á formar nunca un mogote tan aislado y de tanta consideracion como el Lingion. Puede verse en la vista general del Máyon que acompaña à esta Memoria, el aspecto y proporciones de esta colina.

Geologia.

La composicion petrológica de esta montaña es bastante uniforme, como generalmente sucede en todos los volcanes ó regiones de composicion volcánica, sobre todo si, como acontece en el Mayon, la composicion ó distribucion interior de los diques y capas de las diversas erupciones, no pueden estudiarse en el mismo monte, por la falta de uno de esos barrancos profundos, como los clásicos del Bove en el Etna y el de las Angustias en Palma. La hermosura y regularidad misma del Mayon, ocultan hoy por hoy los detalles de su estructura ó esqueleto interior; pero no perdemos la esperanza de allegar tal vez algunos detalles más de los que hoy conocemos, si volvemos á visitar este sobérbio coloso, en meses y dias mas apropósitos y convenientes para su estudio que los de que pudimos disponer en nuestra visita de los últimos dias de Dic^e del año anterior[1].

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[1] Reinando entonces con toda su fuerza la monzon del N. E. que directamente azota toda aquella costa, los caminos secundarios y mucho mas los barrancos y laderas del monte, estaban intransitables

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Tomado en conjunto, el Mayon se compone de rocas esencialmente basálticas, formadas de feldespato y augita, como elementos dominantes que imprimen carácter á las masas pétreas del monte; ya compactas, en los diques; ya lávicas ó esponjosas, en las corrientes de lava; ó ya escoriformes y metamorfizadas por la accion de los manantiales gaseosos ácidos del mismo volcan, en las deyecciones actuales.

Las lavas fragmenticias que actualmente arroja, presentan variedad de aspectos petrológicos. Como tipo mas flúido hemos recogido, todavia caliente, en el barrio de Bucton, una lava basáltica esencialmente augítica y algo escoriforme, que casi puede designarse con el nombre de escoria, aunque no tan esponjosa y tan característica como las que se encuentran por ejemplo en el volcan de Taal.

Tambien arroja numerosos conglomerados que llamamos lávicos, para indicar su formacion en trozos de verdadera dolerita compacta; á veces de gran tamaño, envueltos en otra lava basáltica semivitrificada que ha servido de cemento, pero *por la via ígnea*, para distinguirlos de los conglomerados de materiales volcánicos sedimentados ó depositados por la accion del agua. En estos conglomerados, se observan sobre la dolerita, que es la roca más feldespática, costras de yeso cristalizado, cristalino y fibroso, formado por la accion de los gases sulfurosos sobre la base calífera del labrador, y aun de la augita; como un curioso efecto de la accion metamórfica actual de los gases volcánicos, sobre las rocas tambien volcánicas.

Se presenta tambien á veces la dolerita muy descompuesta y kaolinizada, notándose en este caso que apénas se forman las costras de yeso, sin duda porque la descomposicion se ha hecho bajo la accion de otra clase de vapores que producen otros compuestos.

Las doleritas compactas y poco descompuestas, que forman algunos de esos conglomerados lávicos, parecen revelar que han

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y á veces completamente inaccesibles. En nuestra ascension, el viento fuertísimo, la lluvia y la multitud de sanguijuelas que se nos pegaban en todo el cuerpo, aumentaban la enorme fatiga de la subida, por pendientes de 30.° y 40.°, é impedian hacer buenas observaciones. En tiempo seco (Abril y Mayo) solo hay que vencer la fatiga natural de la difícil subida.

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sido arrancadas de las paredes de los conductos volcánicos, cementándose en la lava escoriforme vitrificada que los envuelve, y permaneciendo muy poco tiempo en este estado, dada su escasa descomposicion; así como los trozos mas descompuestos han sentido la influencia del calor y de los gases de las lavas, permaneciendo mas tiempo en los espresados conductos interiores.

El estado pastoso, semisolificado en que las lavas se presentan puede esplicarse suponiendo que el laboratorio volcánico de donde proceden, está situado á gran profundidad, enfriándose ó solificándose considerablemente, ántes de llegar, con alguna lentitud, á la superficie de las laderas ó bocas de deyeccion.

Esos mismos conglomerados, parecen tambien demostrar que, el esqueleto del Máyon, está formado esclusivamente de doleritas, que son las rocas arrancadas de las paredes interiores; y que el tipo mas verdaderamente basáltico proviene de las erupciones mas modernas ó contemporáneas.

Las doleritas son exactamente iguales á las que presenta el Súngay y el Taal en Batangas, y mas especialmente á las del Maquíling; y segun Roth, que vió los ejemplares recojidos por el viagero Jagor, son tambien idénticos á las del Etna, hasta el punto de no distinguirlas entre sí. Están compuestas de feldespato labrador y augita, con algunos granos de olivino y hierro magnético; presentándose de un color gris ó rosácea y á veces hermosamente porfídicas, en cuyo caso los elementos accesorios casi desaparecen.

Sin embargo, en nuestra ascension, hecha por la parte del E.N.E., en la jurisdiccion del barrio Bonga, encontramos á 1000 y 1500^{m} de altura, en el caúce del rio Bulauan y de los arroyuelos afluentes que tuvimos que atravesar, un basalto lávico un poco celuloso, pero no escoriforme, en algunos parages y con carácter porfídico; constituyendo una verdadera basanita que, por el yacimiento, parecia constituir una no muy antigua corriente de lava.

Subiendo el monte[1] se encuentran en primer término,

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[1] Drasche cita solo la ascension de dos Escoceses, la del viagero Jagor, y la súya propia; y como ésto podria hacer creer á muchos, que nádie más habia subido al volcan, debemos manifestar que ya en 1592

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con suavísimas pendientes, capas de arenas sueltas puramente volcánicas, separadas de trecho en trecho por una especie de lechos de cantos mayores, de suerte que figuran una especie de peldaños espaciados de 50 á 30 metros, los cuales han debido evidentemente formarse por avenidas y erupciones sucesivas.

Mas arriba, la pendiente va pronunciándose, y los materiales de las arenas se hacen mayores; desapareciendo á los 600 metros la region cultivada[1], que se sustituye por el bosque maderable. Sucesivamente se va éste haciendo mas claro y mas raquítico, y se presenta el suelo mas compacto, con las corrientes de lava que hemos indicado mas arriba.

A los 1500 metros de altura sobre el nivel del mar, la vegetacion está casi esclusivamente compuesta de altas yerbas, y la pendiente de las laderas es pronunciadísima y sumamente fatigosa. Sobre la masa basáltica del lecho del rio Bulauan, se ven en sus laderas materiales gruesos incoherentes, de la misma naturaleza que los recojidos en Bucton à 700 metros de altura, con la diferencia de no encontrar en aquellos los encostramientos de yeso que en estos se observaban con abundancia.

Más arriba, los materiales sueltos van siendo mas numerosos y mas variados, aunque todos ellos revelan por su aspecto exterior, generalmente recubierto de una capa de óxido de hierro pardo, que no son productos de muy modernas erupciones; lo cual tambien comprueba la vegetacion existente, que, aunque raquítica, llega por aquella parte hasta muy cerca de la cumbre[2]

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se cita la ascension de dos PP. Franciscanos, uno de los cuales encontró *dos bocas*, que le impidieron avanzar, y el otro recogió una buena porcion de *azufre*. El 11 de Marzo de 1828, el Capitan Don Antonio Sigüenza, subió tambien al volcan, obteniendo por este hecho una medalla de la Sociedad Económica. Por último, en los pueblos que rodean al volcan, viven algunos Españoles y muchos Indios que han llegado á la cumbre en épocas de tranquilidad volcánica.

(1) Es necesario no olvidar que nos referimos al N. E. de la montaña; hácia el S. la parte cultivable está mas baja..

(2) Este hecho lo hemos comprobado personalmente sin embargo, el Señor Drasche dice (Bol. T.° 8°, pag.ª 334): "Pasando al pié del Albay, tuve ocasion de examinar atentamente la montaña por su *parte oriental*. El bosque apénas alcanza aquí la cuarta parte de la altura y siguen hasta la cumbre montones de escorias." Es posible que este hecho se refiera *á la parte meridional* por donde subió, y en la que efectivamente se verifica esto.

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El estudio de esta cumbre no ha podido hacerse, hasta el presente, ni aun por aquellos que la han alcanzado en épocas de tranquilidad volcánica de la montaña; pero por sus confusas ó muy concisas descripciones parece deducirse que no existe un verdadero cráter en forma de caldera, y que si ha existido, probablemente ha debido rellenarse por los materiales del interior que, lanzados con escasa violencia y en sentido muy vertical, han podido caer nuevamente dentro, obturando el cráter. Lo que hoy puede verse, ya sea desde cualquiera de los pueblos de la falda, ya desde la ladera misma, donde nosotros lo contemplámos bastante cerca, es una especie de enorme criba, formada por una escombrera de grandes cantos, amontonados en desórden por entre los cuales salen numerosísimos dardos de vapores que reunidos forman el inmenso penacho del volcan; pero parece indudable que la lava solo la emite ya, á lo menos en la actual erupcion, por las bocas secundarias ó hendiduras del S. de la montaña; y probablemente ha debido suceder lo propio en las últimas erupciones anteriores, si se atiende al estado de la vegetacion de las laderas hácia todos los rumbos.

Así como, hácia el S., la vegetacion termina à unos 700.^{m} de altura sobre el nivel del mar, acabamos de ver que, hácia el oriente llega hasta muy cerca de la cumbre, y otro tanto sucede hácia el N. y hácia el O.; indicando esto que los productos de las erupciones, hace mucho tiempo que no salen en esas direcciones, y que, por lo tanto, si la salida de los materiales interiores persistiera en el mismo sentido en que hoy se emiten, la montaña avanzaria sobre el mar hacia el seno de Albay. Además, esta persistencia en la salida de las lavas hacia el S., demuestra que la ladera del N. es mas resistente y se han solidificado y rellenado todas sus grietas; ó bien que el conducto ó chimenea volcánica presenta un buzamiento hácia el N. que con el tiempo destruirá la actual regularidad de la montaña.

En cuanto à la composicion de los cerros aislados de Tancalao y Lingion, el primero, además de contener una dolerita idéntica á la del Máyon, presenta un feldespato blanco mate, en fajas ó capas que parecen concrecionadas, con cristalillos de mica negra y algunos que parecen de broncita; y un dique, formado de una retinita gris, con venillas negras en dos sentidos

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casi perpendiculares, de una especie de obsidiana, y cristalillos, tambien de mica, interpuestos en la masa total, resquebrajada de tal modo que, deshaciéndose en granillos, tal vez pudiera clasificarse mejor como una verdadera perlita ó galliacea, teniendo en cuenta su índole basáltica.

El cerro Lingion está esencialmente compuesto de doleritas lávicas oscuras, de las que forman un tránsito al basalto. En la superficie, se encuentra gran cantidad de rapilo, formado de feldespato, y numerosos cristalillos de augita; pero no está solo y esclusivamente compuesto de estos materiales incoherentes y deleznables, como Drasche supone[1], atribuyéndoles el orígen de la forma de esta colina, puesto que, en algunos barrancos, se descubren las doleritas lávicas que hemos indicado y otras rojas escoriformes. Por otra parte, ya dijimos antes que no se comprende como, aun suponiendo que estuviera compuesto de ràpilos, ha podido llegar á adquirir la forma cónica que esta colina presenta.

En cuanto á los cerros que forman y rodean al actual emplazamiento del pueblo de Cagsáua (Daraga), y los que forman la baja y pequeña península de los pueblos de Bacacay y Líbog, estan compuestos de tobas volcánicas, peperinos y brechas de cantos y elementos doleríticos, empastados en una especie de arcilla gris, exactamente igual á las cenizas del volcan, oxidada en muchos puntos y convertida en una especie de ocre pardo ó amarillento. La existencia de estas colinas debe pues ser posterior á la aparicion del focó volcánico del Máyon, á no ser que puedan relacionarse sus materiales á los focos ya apagados del Masaraga ó Malínao. Este hecho, solo podrá verificarse en el supuesto de que las rocas volcánicas de estos últimos focos estinguidos, presenten un tipo ó composicion distinta de las que caracterizan al Mayon.

Por lo que se refiere á la clasificacion del estado de actividad de este volcan, si bien presentaria cierta utilidad práctica, para calcular el peligro de las poblaciones que le rodean, no creemos que sea fácil de hacer, con los actuales conocimientos, sobre esta delicadísima rama de la geología moderna. Drasche,

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(1) Bol. de la Com.ª del Mapa Geol. de España T.° 8.°, pag.ª 338.

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admitiendo los periodos de actividad volcánica que Stör distingue, supone que el Máyon ha entrado en el 2.°, ó sea en él de derrame de torrentes detríticos de lava[1]

No sabemos hasta que punto puede ser generalmente cierta esta clasificacion, puesto que, circunscribiéndonos á los estrechos límites de la historia conocida del Mayon, vemos que, unas veces ha presentado solamente ligeras erupciones de ceniza; otras esclusivamente derrames de lava; y, casi siempre, salida de ambos elementos eruptivos, pero en un órden inverso al que como mas general admite Drasche, es decir, precediendo las cenizas á la deyeccion de las lavas ó á los períodos en que redobla su actividad. Este hecho, puede esplicarse fácilmente, en el supuesto probable de que las cenizas volcánicas provengan de la trituracion ó rozamiento de las rocas que más ó ménos intercepten los conductos interiores, suponiendo que la primera fuerza impulsiva de la erupcion límpia, por decirlo así, los conductos atuidos, arrojando al exterior los materiales pétreos y pulverulentos que se producen.

Admitiendo, en todo caso, la clasificacion de Stopani, no para caracterizar el estado más ó ménos avanzado de decrepitud del volcan, sino como carácter ó *fase* de sus erupciones; podremos decir que la de 1814 presentó la *pliniana ó de explosion*, y que la actual puede designarse como de *deyeccion ó estromboliana;* presentándose en los períodos intermedios, de aparente tranquilidad, bajo la *fase* de *simples emanaciones ó de solfatara.*

Supone ésto que no vuelva ya á presentar jamás la fase explosiva ó pliniana? Nádie creemos que fuera capaz de asegurarlo, no solamente para este volcan, cuyas significativas deyecciones actuales y la presencia permanente de su inmenso penacho, nos avisan el peligro de tal suposicion; sino que en el mismo volcan de Taal, que Drasche supone en el 3.° de los periodos de Stör, y aun en el Maquíling ó en el Ysarog, que en todo el periodo histórico conocido, han permanecido en el mas absoluto silencio, y en cuyos cráteres existen árboles seculares que hacen retroceder mas la fecha de esa tranquilidad; pueden muy bien ocurrir todavia catástrofes desoladores, que

(1) Supone que el 1.° produzca solo deyeccion de lava y el 3.° erupciones de ceniza.

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den el mentís mas absoluto á todas esas hipotéticas suposiciones; arrojando por sus antiguos cráteres, ú otros que al efecto se abran violentamente, torrentes de lava y de fuego, que siembren la desolacion y el espanto en las fértiles comarcas que les rodean.

Los pueblos situados en la base del Máyon, saben perfectamente la peligrosa vecindad del coloso que les domina, y sin embargo, su poblacion aumenta cada dia: y es que sus laderas alimentan una sobérbia y vigorosa vegetacion, que constituye la riqueza de la provincia; y presienten que, como dice Sir C. Lyell, de las calamidades que forman el obligatorio lote de la humanidad, las mas desastrosas, deben atribuirse á las causas morales, y no á las físicas; á los sucesos que el hombre hubiera *podido* domeñar, más que á las catástrofes inevitables que resultan de la accion subterránea.

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ABSTRACT

OF A

MEMOIR

ON THE

EARTHQUAKES IN THE ISLAND OF LUZON

IN 1880.

BY

DON JOSÉ CENTENO Y GARCIA,

ENGINEER AND INSPECTOR GENERAL.

TRANSLATED BY

PROF. W. S. CHAPLIN.

READ MAY 30TH, 1882.

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SECTION I.

General Observations and Effects.

I

Description of the Earthquake in Manila.

Since the remarkable catastrophe of 1863, which destroyed its principal buildings, burying under them many victims, this capital has enjoyed a relative rest which has been improved to develope the wealth of the country. The shocks of 1869 and 1872, not being accompanied by disastrous effects, did not retard this prosperity, and all who had lived here since that time saw with the utmost satisfaction the rapid progress which during the last ten years had been made in commerce, navigation, industry and even in the arts; but this lively satisfaction was imbittered from time to time by the recollection, the sad tradition, the quasi geological law, that from the conquest down to our days these phenomena at intervals of ten or twenty years neutralized by their fearful consequences the progress made in the mean time.

On the fourteenth of July 1880, at 12.53 at night, the first shock happened, and this, although short, was the most severe which had been experienced in Manila for several years. The motion was found to be in two directions, nearly at right-angles with each other, the first from South-east to North-west and the second from South-west to North-east, which seems to indicate the existence of two distinct foci of equal intensity of action, one in the second quadrant and the other in the third, since the amplitude of the oscillations recorded on the horizontal seismometer at the meteorological observatory of this capital were respectively 5° 25′ for the first, and 4° 58′ for the second. Figure 1, which together with the four following are taken from the publications of Father Federico

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Faura, S. J., Director of the Meteorological Observatory, shows clearly the directions and relative intensities of the horizontal motions.

There was also in this earthquake some movement in the vertical direction, as the vertical seismometer moved through four millemetres of its scale.

Within an hour and a half after the first shock two new shocks were felt; these in Manila were unimportant, but in other places, as we shall see further on, they were more considerable, as in the provinces of Laguna, Morong and La Infanta, where during that night and the following day the recurrences were more frequent and the effect on buildings greater.

After this first shock, which, without producing great alarm in the vicinity, doubtless served as a salutary warning to take precautions which avoided greater misfortunes in the following shocks, the ground remained undisturbed during the 15th and 16th. On the 17th two slight shocks were again felt, which, although feebler than those of the 14th, indicated that the ground was not yet at rest; and indeed at 12.40 P. M. on the 18th, the fearful phenomenon was repeated in all its intensity, and in 70 seconds, which seemed however interminable, tumbled down a large portion of city and terrified the inhabitants, who, losing the innate confidence in the soil on which they stood, felt under their feet a force invisible, immense, mysterious, which in sepulchral silence with terrible might destroyed in a few seconds the work of many years, and threatened them with an instant and strange death. The inundation which rolls forward and engulfs thousands of people; the lightning which causes such terror and destruction with its thundering explosions and phosphoric light; the grand volcanic paroxisms with their flames and their showers of burning ashes which bury great tracts of country, and with their rivers of lava which overwhelm and destroy everything in their paths; all these phenomena have a character of grandeur which, while it overpowers the mind, invites it to comtemplate them and charms it with their colossal splendor. All these phenomena offer to the imagination an imminent

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danger, a death more or less probable, against which however there is always the hope of defending one's self. But the earthquake with its sombre silence, its unknown origin, its sudden and boundless effects, which may be a few cracks in the walls of buildings, or the disappearance of one or a hundred villages with all their inhabitants, this phenomenon so treacherous and at the same time omnipotent overwhelms the mind and leaves an impression never to be eradicated.

The pendulum of the seismograph at the "Ateneo Municipal" traced a line which indicated the motions of the ground, giving a figure so complicated that it is not possible to follow the line in its full extent, and even less to describe the complicated series of motions which caused it. We reproduce the figure (Fig. 2) from which may be seen the principal oscillations with their directions and relative intensities; and we copy entire the observations made and published by the observatory of the Ateneo Municipal on the 19th of July.

"July 18.—Sky covered with cirrus clouds all day; winds constant from the third quadrant; barometer rising; temperature moderate; evaporation 6.1 millimetres.

"*Note:*—At 12.40 in the night there was an earthquake which showed oscillation, trembling and what is commonly called rotation. It is not possible to record here all the movements of the pendulum, owing to their number and variety. To satisfy the desire expressed by many people we reproduce the figure described by the pendulum of the horizontal seismograph, which we think worthy of extended study. Today we limit ourselves however to the indication of the principal directions and amplitudes of the motions, leaving the remainder until the figure giving all the motions has been lithographed:—

"First maximum oscillation=from E. 5° S. to W. 5° N. Amplitude of the greatest oscillation in this direction is 22° in the slope of the seismic wave, 11° to the East, and 11° to the West.

"Second Maximum Oscillation=from South-west to North-east; amplitude 19°, but with the difference that the greater part of the motion 10° 10′ was towards the South-west, and

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the remainder 8° 50′ towards the North-east.

"Third Maximum Oscillation=from N. 4° W. to S. 4° E., amplitude 16°, of which 9° was towards the South and 7° towards the North; consequently the impulse appears to have been from the North, towards the South.

"The index of the vertical seismometer was moved 34 millimetres from its position."

From the time of the heavy shock of the 18th until nine o'clock on the morning of the 19th according to the observations, there were felt many weak oscillations and shocks, all in directions from the South of East to the North of West.

Not only did the oscillations and shocks of little intensity continue until nine o'clock in the morning, the hour at which the observations cited ended, but they continued from that time almost without interruption, some easily perceptible, and others only recorded by the seismograph, until 3.40 o'clock on the afternoon of the 20th, when a new catastrophe came again to try our hearts, already disturbed, not only by the deep impression made by the former earthquake, but because the persistency of the motions and the continued vibration of the soil indicated clearly that under our feet that terrible motor, that mysterious force which in an instant might annihilate us, was still acting.

The violence and intensity of this second shock were greater even than of that of the 18th. And although the amplitude of the oscillation, as given by the record of the seismograph (Fig. 3), did not show as great an angle as the maximum of the 18th, the greater intensity ought to be attributed to this fact, that on the 20th the pendulum after starting was not allowed to finish its oscillation, but was forced to move in other directions without completing its curve on the plate, thus, as is clearly shown in the figure, the lines *aa*, *bb*, *rr* do not mark complete oscillations, but semioscillations. The pendulum, descending to the center of the plate with a velocity which would have raised it to a point almost as high as that reached on the other side, was moved by a force which not only destroyed the motion already possessed by the pendulum, but constrained it to ascend again to a height almost equal to

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the first, which in reality represented an amplitude much greater than the 22° that had been recorded on the 18th.

The observations made at the meteorological observatory of the Ateneo describe the earthquake thus:—

"At 3.40 on the afternoon of the 20th strong shock felt; duration 45 seconds. First maximum oscillation; direction from S. E. 15° N., to N. W. 15° S.; amplitude 17°, of which 8° to the N. W. and 9° towards the S. E. Second maximum oscillation from S. E. 5° N., to N. W. 5° S.; amplitude 12°, of which 5° towards the E., and 7° towards the W. The index of the vertical seismograph was moved 22.5 millimetres from its position."

Some days after the earthquakes, the director of the observatory, Father Federico Faura, published a résumé of the observations in which this description was somewhat modified, as it was pointed out that the amplitude of the second maximum oscillation ought not to be 12°, but that this 12° was the amplitude of a semi-oscillation.

The pendulum continued during the remainder of the afternoon to oscillate in a way which was most disheartening to those of us who know that the instrument showed motions in the earth, although we could not perceive them. At 8 o'clock in the evening one of the vibrations was felt very perceptibly, and at 10.40 occurred the third earthquake with shocks more violent and irregular even, according to the feelings of many people among whom was the writer, than the former ones. Its duration was also greater than that of the earthquake in the afternoon, amounting to 55 seconds, and the vertical shocks moved the index of the vertical seismograph 28 millimetres instead of 24 as in the former case.

The situation could not be more trying; the shocks occurred more frequently; the intensity and violence of the motions increased; and many persons fearing any one of the thousand catastrophes which might happen, sought safety in boats on the river or bay. Considering the topographical situation of Manila, with the bay on one side and the lake *Bay* on the other, menaced thus by these two bodies of water which might in a few minutes inundate the whole low plain

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which separates them, in which are placed the most considerable villages of the province, these precautions were very proper.

We give here the observations made with the seismograph of the Ateneo Municipal relating to the last earthquake, and published in the papers of the 22d.

"At 10.40 p. m. on the 20th a very heavy shock. Direction of the first oscillation S. W. to N. E. exactly; amplitude 17°, 9° to the S. W. and 8° to the N. E. Amplitude of the second oscillation 10° from E. to W. exactly, 5° to the E. and 5° to the W. Duration 55 seconds. The index of the vertical seismometer was moved 28 m. m."

In Fig. 4 may be seen the record left by the pendulum on the plate; and it is to be observed that, as in the two great earthquakes which preceded this one, the directions from the second toward the fourth quadrant are greatly in excess; so much so in the shock at 3.40 p. m. on the 20th, that this direction alone is observed, and in the last shock the two directions again appear as in the first of the series; with only this difference, that in the former the energy of the motions from the second to the fourth quadrants was greater than that of the motions from the first to the third, and in the latter the contrary was the case.

After this last great earthquake the vibrations of the earth gradually diminished until the pendulum stayed at rest for long intervals of time, a thing which had not been observed from the 18th until 3 p. m. on the 21st. These feeble shocks which were felt at irregular intervals, far from alarming us, rather reassured us, as their intensity became less and less and the intervals between them became greater and greater. Only at daybreak on the 25th a single shock was felt somewhat heavier than these others since the 20th, but this was without notable importance and left on the seismometer the curve represented in Fig. 5, in which only a single direction, that from the first towards the third quadrant, is seen; the direction from the second towards the fourth quadrant, which had been in former earthquakes the source of the most persistent and greatest motions, having consequently disappeared. The

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amplitude of the oscillation in this last shock was only 4°, and the index of the vertical seismograph was only moved one millimetre.

In the latter part of July there was published, as we have before said, by the Director of the Meteorological Observatory a résumé of the observations made on the earthquakes between the 14th and the 25th of the month, in which after describing in detail the apparatus which had served to make the horizontal and vertical measurements, he proceeds to give an account of the earthquakes which had happened in the provinces in the Northern part of Luzon in the months of April and May, and deduces from the accounts which he had received concerning the direction of the motions, *that the center of seismic oscillation coincides with a volcano which has been for a long time extinct, situated between Lepanto and Abra in the central mountain chain of Luzon, in latitude 16° 22′ and longitude 127° East of the observatory of San Fernando* (1) (2).

One would be led to suppose, from the fact that the Director begins his observations in this way, that the earthquakes of April and May, as the Director clearly indicates, continued until the beginning of July, and had a connection with those of July 14—25 which we have just been describing. It will be of interest for us to test in some way the existence of this center of seismic oscillation, of this long extinct volcano situated in the central mountain chain, and marked with such certainty by the illustrious director. We have travelled over the districts of Lepanto and Benguet for some days; we have tried to reach the point which he has indicated by its latitude and longitude; we have taken on the spot notes which we will further along set down on the intensity of the phenomena in the neighborhood of the supposed focus; and we expected logically that there it would have been felt with greater intensity than elsewhere in Luzon. Nowhere have we met any-

(1) This geographical position does not correspond to any point of Abra or Lepanto, but rather to a point to the South of the latter, and in the center of the district of Benguet.

(2) *Longitude 121° East of Greenwich.*

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thing to confirm this hypothesis, neither extinct volcano, nor indications of an ancient or modern volcanic formation. There are only found plutonic formations constituting the great mountain chain, metamorphic formations (schists and slates of various kinds), sedimentary, lower tertiary, or perhaps cretaceous formations, and modern alluviums. We learned that the effects of the earthquakes had not been by far as great as in the provinces in the center of Luzon; and finally upon visiting the point which appears to agree, by its situation between the two districts, with the supposed focus of seismic irradiation, which was the high mountain called Dalá cited in various works, and in some of them as volcanic, we met at 1600 metres above the sea-level with magnificent tertiary limestones, which by their presence protest against the theory of a volcanic origin of this mountain, which by a printer's error Father Faura has placed between Lepanto and Abra while it really is between Lepanto and Benguet. In spite of this negative testimony let us not venture to form an opinon on Father Faura's hypothesis before hearing his statements; let us see whether the data which he has used will not clear up our doubts on the subject. We have conferred with him and he has frankly shown us that in proposing this hypothesis he only considered the reports, more or less exact, which he had received from the provinces of the North, and that with them and a map before him he thought he had found the focus of seismic irradiation, which according to our view does not exist.

We have insisted at some length on this point, because the hypothesis is already laid before the public, and by it an important and still obscure problem of geology is solved or professed to be solved, and the author of this hypothesis is such a respectable gentleman as Father Federico Faura. Our silence would have been construed either as blameworthy forgetfulness or as assent to his opinion.

He proceeds in the résumé to analyze the different figures which were drawn on the seismograph by the pendulum; he then gives some reflectious on the various foci of seismic irradiation, on their positions and on the changes which these

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foci have undergone from one earthquake to another; and he concludes with the following paragraph, which we transcribe because it condenses the important part of the observations:—

"We will now review, and fix what the figures tell us. In that of the 14th, which is the one which is numbered 1 in the first plate, we note two centers of seismic irradiation, one in the second quadrant where the earthquake began, and the other in the first quadrant where it ended. On the 18th we again find the two foci just mentioned, but other new ones appear, which drive the pendulum in all imaginable directions, as may be seen in Figure 2, plate 1. The record of the earthquake of the afternoon of the 20th, in which it may be observed that the focus of the second quadrant is working with wonderful violence while the others have disappeared, is given in Fig. 3, plate 2. Now we will examine Figure 4 plate 2 which shows the fearful shock of the night of the 20th; we notice a very great change with regard to the foci of seismic irradiation; the oscillations from East to West, which correspond to the focus which was working before with so much violence, are gradual and of much less intensity; on the contrary, those from N. E. to S. W. show a great force of undulation from these points. Finally let us observe Fig. 5, plate 2, which shows the last important oscillation at daybreak on the 25th; it will be seen that only the focus in the first quadrant now appears working with very slight intensity, the other foci disappearing completely. We will not now try to deduce any consequence of the results thus far pointed out; we have only wished to point them out in order that they may be studied by others for themselves without being influenced by our opinions."

It is much to be regretted that the learned Jesuit, who at the time of the earthquake was always beside his instruments in an observatory perfectly supplied with scientific instruments of all kinds, to whom were immediately sent all the official telegraphic and postal notices on earthquakes from the provinces, in order that with them, with his instruments and with his science he might obtain some result from their study; it is lamentable, we say, that that scientific gentleman left some

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days without seeking to deduce the consequences from his observations, only indicating the facts observed in order that investigators whe had no instruments, no observatory, no time at those sad moments to devote to scientific speculations, might consider them without being influenced by the opinions of Father Faura.

If, as we believe, and as appears from his own words, he had formed an opinion concerning the phenomenon, although not exact yet with some foundation, he ought to have published it, even though it might have been with the reserve which in this kind of studies, so new and complicated, ought always to be claimed; and in so doing he would have rendered a service to science, which today uses all kinds of observations, however insignificant they may be, to deduce from them some valuable result. The Scientific Commission recently created in Zurich under the direction of the learned Prof. Albert Heim to study earthquakes, begins by recognizing its ignorance on this class of phenomena, and invites all persons interested in science, not only in that nation but in the whole world, to collect and send to the commission facts and opinions, however unimportant they may seem; and it carries its kindness and good intention even to the point of printing and circulating most detailed interrogatories, so that those who wish to contribute to this grand work may do so with greater facility and certainty. If that commission asks aid from the whole world, with what gratitude would they have received the deductions, the result of the studies on the Luzon earthquakes of July, made by Father Faura. For our own part, we must declare freely that we should have had much greater satisfaction in following the opinion of Father Faura if it had convinced us, than in sending out, alone and unguided by Father Faura's theories, our own opinions full as they are of doubts, reserves, and vacillations.

II

General Remarks on the Effects produced.

It is truly wonderful that with such violent shocks in all directions, with such great movements as were experienced

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during the three great earthquakes, there remained standing in Manila a single building of rubble masonry. We freely confess that after the earthquake of the 18th we expected to find the town in ruins; and we could not explain the good condition of all or almost all these masonry buildings. They were without apparent injuries; although in very bad repair, their walls falling to pieces, their frames rotten, the partitions broken or tumbled down, yet they were standing and without being notably or even very perceptibly out of line.

We were equally surprised after the shocks of the 20th, especially as the buildings had already been shaken; but the effects were not as great as we all expected they would be, bearing in mind that some of the oscillations had amplitudes greater than 22°, and that the index of the vertical seismograph was moved 34 millimetres, and considering the energy which these motions indicated.

It would be too long a task to describe all the effects of the earthquakes on buildings; and further, as the only object of such a description would be to determine the direction and nature of the motions, which we already know with great certainty from the records of the seismometer in the observatory, we have thought best to omit this description. Those who wish to investigate this subject, can find it given with minute details in the reports made under the Inspectorate General of Public Works.

We shall then limit ourselves to a few general considerations, which may, if we are successful in presenting them, be found useful in reference to future constructions in Manila, with regard to the methods of erecting buildings, as well as to the sites chosen.

In the first place, and as a general rule, it is worthy of notice, that the greater part, if not all, the cracks which have opened in the ground, the upheavals of the surface, and even the depressions which have been observed in some places, have always taken place in the vicinity of rivers, or estuaries (marshes) or the sea. We have confirmed this, not only in Manila, but in various other places in Luzon, and we have always found that this class of phenomena present themselves

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in the neighborhood of old watercourses or of those formed by recent inundations, where the sudden shocks produce in the superficial and, so to speak, spongy formations unequal motions, according to the form and nature of the older formation on which they repose; and consequently cause upheavals, fissures, depressions and perhaps submersion of portions of the soil. On the banks of the river Pasig and the shores of the marshes in the neighborhood of Manila these effects were to be clearly seen; and it may be set down as a general rule that the buildings situated in the immediate vicinity of these bodies of water suffered much more than those further away. A good example is the suburb San Miguel on the right bank of the Pasig, which is composed mainly of well-built structures, and which suffered much more than other suburbs further from the river, whose buildings were badly built and out of repair. In the Palace of Malacañang, the residence of the governor, situated close to the same river, besides great damages caused by the three great shocks in the old part of the edifice, a fissure two centimetres wide and approximately parallel to the watercourse was formed, causing the fall of a great part of the masonry wall which ran along the boundary-line of this enclosure. That fissure some 40 metres long, although narrow and probably partly filled by the falling in of its sides, could be sounded to a depth of four metres, which indicates that its depth was much greater when it was first formed; it may be safely assumed that it traversed the whole modern fluvial alluvium, and reached the volcanic deposit which forms the basis of almost all the province of Manila and part of Bulacan.

This recent alluvium may be supposed to be more yielding, more impregnated with water, in short, more spongy in the localities now passed through by streams of water than in dry regions, and that in the former places the sudden shocks of the earthquakes produce irregular motions which give rise to fissures. Through these fissures the compressed water which fills the soil seeks to escape, carrying with it decomposing vegetable materials which give to the water a dark color, a nauseous odor, or sometimes a sulphurous one, producing great

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alarm on the part of some persons, who imagine that every fissure is the opening of a volcano.

The same effects which we have just described on the Pasig, took place, but on a much greater scale, in the region of the Grande river in the province of Pampanga (Rio Grande de la Pampanga) which extends from Cabanatuan in Nueva Ecija to mount Arayat. In this region, concerning which we shall speak more in detail further on, in certain places there were formed fissures some kilometres long and some metres wide, which converted that locality into a real net through which three months afterwards, though continuous rains had undoubtedly contributed to fill these cracks up, we had great difficulty in travelling, as at every instant we were in danger of falling into the fissures.

Analogous, though less violent, effects were observed in the region of the river Agno, in the province of Pangasinan, in the villages of Bayambang and Alcala, on the river Grande of Tarlac (Rio Grande de Tarlac), in the district of Aguso, and in general on all the rivers of wide beds which traverse alluvial plains; so also on the coast near the mouths of great rivers, as in the villages of Mamban and Atimonan in the province of Tayabas, situated on alluvial formations, where there were fissures near the sea of the same form and identical origin with those above mentioned.

Besides these effects on the ground, against which there is no means of protecting buildings except by removing them as far as possible from the water and building them of light and elastic materials, we ought to consider the effects observed in the buildings themselves, in order to deduce from them if possible the modifications which ought to be introduced in future structures.

The author now enters into a practical consideration of the best forms of constructions followed in this country.

SECTION 2.

Local Observations and Effects.

This section will include the local observations and effects in a great part of the island of Luzon; and for the purpose of

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establishing some order in the description, we have divided the island into three zones, that of the North, that of the center, and that of the South, which will correspond to as many chapters; and in a fourth chapter will be given a résumé of all the observations, in order to deduce the extent of the zones of disturbance.

I

Effects observed in the provinces of the North of Luzon.

PANGASINAN.

As has already been mentioned, we began our examination of the island of Luzon in the province of Pangasinan, landing at Sual and passing through the villages of Luigayen, Bimaley Dagupan, Mangaldan, San Jacinto, Manasag, Binalonan, San Manuel, Urdaneta, San Carlos, Malasiqui, Bayambang, and Alcalá.

The effects produced generally by the earthquakes of July were not nearly as great or as disastrous in this province as in Manila; not so much because the vibrations were less intense or less numerous, but because the principal masonry buildings, the churches, the parochial houses, the court-houses, and a very few private buildings in the more important villages, are covered with galvanized iron or with *nipa*, very few buildings being covered with tiles. Besides, the scarcity of building stone in this flat province where almost all the soil is alluvial has rendered the use of brick obligatory, so that the masonry is much superior to that seen in the central provinces, where generally volcanic stone is used.

From all the reports which we received from the rectors of the parishes and the principal persons in the villages which we passed through, as well as from the official records which were placed at our disposal by the governor of the province, it is evident that of the three great earthquakes only that of the 18th was felt with great intensity, the two of the 20th having been of little importance, and the feeble shocks which before and after those days were felt so frequently in Manila passing unnoticed. Further it is to be remarked, from the effects

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noticed in the ground and on buildings, as well as from the reports given by the persons above named, that the intensity of the earthquake of the 18th was less and less from the South-eastern portion of the province towards the North-western portion, so that in the villages situated around the gulf of Lingayen (Sual, Lingayen, Bimaley, Dagupan, etc.) there were only the very slightest injuries to masonry buildings, even those covered with tiles; while in other villages in the interior (San Jacinto, Malasiqui, Bayambang, etc.) the earthquake left very evident marks of its influence, not only in the buildings which were left in ruins, as the churches of San Jacinto and Malasiqui, but also in the ground, where fissures were produced which can be seen today, as in the villages of Mayambang, Alcalá and Asingan.

From this observation it may apparently be deduced that the general direction of the motion was from the second to the fourth quadrant.

Province of la Union.

In this province situated to the North of Pangasinan the earthquakes of July were felt even less than in the latter province; and the same law of decrement of intensity from the South toward the North, or more exactly from S. E. to N. W., was observed. In none of the buildings, which are of a weak sandstone and not of the best workmanship, have there been great injuries. However some of the earthquakes were felt with the same violence as in Manila; in some of the villages, as in Namagpacan in the northern part of the province and near the seashore, the shock of the 18th was felt with some intensity, but did not however cause any damage; the others according to the statement of the curate were imperceptible. On the contrary in Balasang, a village further inland, but situated toward the East and near the first foot-hills of the mountain chain, the earthquake of the 18th was felt with great force, and caused more damage to the church and convent than happened to any other buildings on the coast. And the two earthquakes of the 20th were felt here, although but feebly.

This remarkable difference between two villages distant

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but a league from each other can not, as we think, be attributed solely to the gradual diminution of the seismic current, for althongh this is very evident in an extent as great as that of the whole island, it is not natural to suppose so sudden a change in a phenomenon which has such wide extent. The notable circumstance that subterranean noises were heard at the instant of the earthquake in Balasang and not in Namagpacan brings up the question whether in the general commotion there were not produced in the mountains near to Balasang subterranean disturbances which increased the vibrations in that limited district.

We think it useless to detail the effects produced in all the villages of the province, and we confine ourselves to a few of the effects, which can show how the violence of the phenomenon diminished, leaving aside the others which are of no interest in our present investigation.

Balasang. It may be remarked that this village situated, as we have said, a short distance from Namagpacan towards the interior, was the point of all the province where the earthquake of the 18th and some later shocks were felt with the greatest intensity. The convent and church were left in a bad condition with cracks in all the arches over the doors and windows, and some in the walls. The ground on which the convent stood was cracked transversely to the edifice, doubtless on account of the pressure which the vertical motions produced, or perhaps on account of bad foundation.

A house built of boards and stucco which stood near the convent lost its walls, leaving in the front only the cane gutters hanging from the eaves.

Finally, the curate of the village, Father Juan Perez, pointed out to us a remarkable effect, which showed the intensity of the shocks. A small tree, called in the country Bag-bag, five metres high, with quite a stout trunk and very few branches, fell during the earthquake tearing out its roots; a remarkable effect, knowing which we can not explain how a single building in the village remained standing. Really we should not have believed such a thing possible, if we had not the statement of such a respectable person.

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District of Benguet.

The diminution of intensity from the interior towards the coast, which we had just observed, led us to visit this district, situated on the East of La Union. We went from Aringay, and passing through Galiano by a road which at some points reaches a height of 1550 metres above the sea, we arrived at La Trinidad, the capital and only Christian village of this district. We were further induced to make this excursion by a story which we had heard, and which was founded on an old chronicle of the order of the Augustines, as, according to this story, at the beginning of the last century quite a large number of cottages, situated to the East of Aringay and occupied by the natives, had disappeared in a great earthquake which produced the submersion of an extensive tract of land.

According to the reports which we received from the commandant of this district, Señor Oraa, and a few which we were able to collect, we were able to conclude that on the 18th of July there were felt not only the earthquake at mid-day, but also two others a short time afterwards; the third which occurred two hours after the first being accompanied by a great subterranean noise. The shocks of the two following days were of little intensity, including those of the 20th, which could not be distinguished by their force from the others. We did not obtain any information from the officers of the Civil Guard, the only Europeans living there, concerning accidents caused by earthquakes; and attempting to verify the story which we have mentioned above, we were unable to gain any facts. Doubtless the topography of the beautiful plain in which La Trinidad is situated might give some reason for conjectures on the subject. A level circular plain about four kilometres in diameter is surrounded on all sides by hills whose height does not exceed 130 metres. In the interior of this plain is a lake whose only outlet is through a fissure toward the north-east, and this outlet perhaps gives rise to the river which empties at Bauang (Union). Looking down on this circular depression from the last heights (1550 metres altitude) which are passed in reaching La Trinidad, the valley

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presents all the appearance of an old crater and it was our first impression that it was one. We, on the following day, examined some of the hills which surround the valley, thinking to find in them the rocks which would confirm or modify our suspicions. Not a single volcanic rock did we find; on the contrary we were surprised to see calcareous rocks with a great abundance of fossils (madrepores and some bivalves) which could not be older than the tertiary period: How shall we explain then this great depression, so regular and flat, whose soil is composed of alluvium washed down from the surrounding hills, and is consequently posterior to them. We are far from suggesting that this is the origin of the story cited, because the time passed is not sufficient for the tradition to die out even among savage races, and because much less is the time sufficient in a geological point of view for all vestiges of such a phenomenon to have disappeared, or for so thick a deposit of alluvium as now covers and converts the plain into a fertile prairie to have formed.

But it occurs to us that perhaps the chronicle is not without foundation, but that an analogous phenomenon independently of any volcanic action may have happened in some other locality in the district, which unfortunately is very little known, if not in La Trinidad; and that by subterranean commotions, produced perhaps by the earthquakes whose action reaches the surface of the ground, a circular valley was formed, the first effect being to inundate the country until the water by its pressure and chemical action made an outlet for itself, leaving dry at the end of some centuries beautiful prairies like the one we are now considering.

We did not think the foregoing observations out of place because they are somewhat connected with our work, and because this district of Benguet by its situation, its delightful climate with a temperature which varies annually between 8 and 20 degrees centigrade, and from many other circumstances, is a very interesting locality in the interior of Luzon, which at no distant day will attract the attention of the government.

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North and South Ylocos

As these two provinces are topographically the same and form a continuous zone from South to North, and as the phenomena observed in both of them are very few and of little interest, we shall consider them together. The provinces are bounded on the West by the China Sea, and on the East by the central cordillera, which separates them from Lepanto and Abra. Throughout the whole territory considered, the earthquakes of July were but feebly felt, and did not produce any considerable effect either in the buildings or the ground. Here, as in the other provinces which we have studied, the diminution in intensity from South to North is to be noticed; and this is confirmed not only on the coast, but also in the interior of the island, since, according to all the reports received concerning the provinces of Cagayan and Ysabela at the time of the earthquke from various residents, only the earthquake of the 18th was felt, and this, although it lasted quite a time, did not cause any injury to the very few masonry buildings which exist in these provinces. As there were no effects to examine in the last named provinces, we did not visit them, saving thus the time which we required in the provinces to the South.

From Tagudin, the first village in the Southern part of South Ylocos, up to Pasuquin near Cape Bojeador in North Ylocos, we could not observe in any of the intermediate villages that there had been any seismic action which merited attention; and in all these places we were assured by the curates that the shock of the 18th was felt, followed for some days by very slight shocks which in many cases were not perceived. From the village of Cabugao towards the north we began to notice injuries to the buildings, which attracted our attention the more because it in a certain measure destroyed the law of decrement which we had before observed; but we discovered that these injuries were not due to the earthquakes of July, but to one which happened in December 1879, which was stronger here than the July ones, and which must have acted over a very small area, as it was felt only in the villages of

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North Ylocos. It should be noted that the effects which we observed in buildings indicated clearly that the law of decrement in the earthquake of 1879 was the reverse of that in the July earthquakes, that is from North to South.

Districts of Lepanto.

Although our journey to Benguet had shown us that no notable phenomenon had occurred in central Luzon, if it were not a slight increase of intensity in the earthquakes compared with the Western coast, we resolved nevertheless to make a new excursion to Lepanto; not so much to widen our field of observation, as to test a theory published by Father Faura concerning the existence of an extinct volcano in this district, which was said to be the probable center of seismic irradiation. We have published our opinion and our observations on the supposed focus elsewhere, and we have nothing to add now; but we have promised to describe the principal seismic effects in this district and we will fulfil our promise.

Our itinerary was as follows:—We left Candon and going through Salcedo passed over the mountain Tila to Angaqui situated on the left bank of the Abra in its high part. Then we passed over to Cervantes, Mancayan, Tubuc, and Mount Datá, returning to Cervantes to go to Cagayan, the principal place of the district. Thence we descended again to the coast, passing the mountains at a place celled Tabalina; and went through Tiagan to Santa Maria a town on the coast to the north of Candon.

In none of the places named, which were composed principally of small huts built of wood, cane, or cogon, could we see any effects of the earthquakes, and the reports which we could collect from the natives agree in saying that the earthquake of the 18th alone was of any importance; the remainder, which were felt until the 20th, were very small and scarcely perceptible. We are able to estimate the relative intensities of the shocks from the high dry stone walls which the natives erect to support their little tracts of cultivated land in the mountains; and the perfect state in which we found these walls indicated that the motions of the earthquakes had

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not been violent enough even to tumble down these weak constructions.

At the metallurgical works at Mancayan there is, besides other structures, a furnace for refining copper with quite a high chimney, which was not injured at all by the earthquakes. The mines at this place have been worked for a long time and in a most economical manner so far as the supporting walls are concerned, and in not a single case did the walls fall down.

Only on the Southern side of Mount Datá were we able to find any considerable marks of seismic action on the ground; and these were due not only to the intensity of the shock, but also to the special configuration of the ground. On the banks of the deep stream, which from its direction appears to be an affluent of the river Suyuc, there were places where the earth had fallen in, where there appeared to be numerous cracks on both banks, though they had but little length.

An analogous phenomenon, but of less extent, happened on the North-east slope of the mountain in the neighborhood of Cayan; we will not describe it, as it offers nothing new.

Zambales.

On the return from the provinces of the North, our assistant Don Enrique d'Almonte (the writer having been taken sick) passed from Sual to the province of Zambales, and in some of the villages gathered information, from which it appears that the earthquakes, except perhaps that of the 18th, were but little felt, and caused neither damage to buildings nor cracks in the ground. We will not give the details of the very slight effects which were observed; we will only add that the mail steamer "Elus" was sailing along this coast during the afternoon and night of the 20th, and that on board of her none of the fearful shocks felt at Manila were noticed.

II

Effects observed in the Central Provinces of Luzon.

Tarlac, Pampanga and Bataan.

The tract of country which extends Southward parallel to the mountain chain of Zambales from the limits Pangasinan,

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including the three provinces which we are about to study, was but little influenced by the earthquakes of July; however it may be observed that their energy was greater in the more distant points, those just to the East of the mountains of Zambales, than in points nearer to Manila, as should be the case according to the law observed in the provinces in the North. In the province of Bataan, which is the most Western one and includes both slopes of Mount Mariveles, the Southern end of the Zambales chain, the earthquake of the 18th had but little intensity, and the others were just perceptible, in no case causing damage to buildings in this province; while in Pampanga and Tarlac the effects were much greater in the villages distant from the Zambales mountains.

In Camiling, Capas, Mabalacat, Angeles, Bacolor, and Guagua, all situated on a North and South line near the mountains, we did not observe any great marks of the earthquakes, either in the buildings or the ground; in other places like Tarlac, Arayat, Santa Ana, Mexico and Macabebe situated further to the East, the effects in the ground and buildings were much greater; for example the church at Mexico was left in such a condition that it was necessary to pull it down, and in Macabebe one of the towers of the church was tumbled into ruins.

Nueva Ecija.

The effects of the earthquake of the 18th of July, the only one which was very heavy in this province, were truly imposing in all the region included between Cabiao and Cabanatuan on one side, and on the other side the river which rising in the mountains on the East of the province and passing through Bongabong, Cabanatuan and San Ysidro finally joins near Mount Arayat with the Rio Chico de la Pampanga forming the Rio Grande de la Pampanga. To the violence of the shocks, there was here joined the circumstance that the soil is of very recent formation consisting of the modern alluvial deposits of the Rio Grande; and these two circumstances together caused great and unequal depressions and numerous fissures, from which water and sand in great quanti-

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ties were discharged, inundating extensive tracts of land and rendering many fields valueless.

The general direction of the great fissures was from East-north-east to West-south-west; and the spaces between these fissures were divided in every direction by others which were narrower (from 10 to 50 centimeters wide) but very deep. Three months after they were formed, although there had been heavy rain storms meanwhile, the fissures were not filled up; and when we visited them many still were of very great depth. Some of the great fissures run in the direction already given from the district of Sapan to Buliran, passing through the village of San Antonio, and having a breadth which reaches in some places 10 metres.

Between the river and village of San Antonio there were two fissures which were so wide as to appear like sections of the earth; the one nearest the river had a breadth of 6 metres, and the other, 200 metres away from the first, a breadthof 10 metres, and the ground between the two sank two and a half metres.

At some points near the bank of the river so numerous were the cracks that the ground presented the appearance of a pavement, the stones of which had been thrown out of position and level. At other places, besides the fissures, there were notable changes of level, so that the surface of the ground was broken into steps as in the case of a farm in the district called Delincuente near the village of San Antonio, where in a sugar-cane field which was originally flat, the surface was so disturbed that in some cases the top of one row of plants fully grown was on a level with the roots of the next, and of the 10 hectares of the field 8 remained valueless.

The width of some of the fissures was so great that in one of them a carabao (boat) disappeared; and we could see full grown trees (*magnifera indica*) hanging by their branches on the edges of the fissures. We might give great numbers of this kind of accidents, but it would only uselessly enlarge our too diffuse account, without adding any facts which can not easily be imagined; such as the partial destruction of a few houses of cane and "nipa," when two or more of the supporting posts happened to fall into a fissure.

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Happily for the unfortunate people, the earthquake happened at an hour (noon) when they were necessarily in their houses, thus avoiding the many accidents and injuries, which would have occurred had they been working in the fields. A single accident of this kind was recorded, which happened on the farm of a man named Juan Fernandez. Three children were playing together when the earthquake began; they were frightened and ran towards the house, which two of them reached; but the third fell into a fissure which opened under his feet and immediately closed again. After the first instants of anguish, excavations were commenced on the spot pointed out by his little companions, and after several attempts his body was found at a little depth, completely crushed.

The vertical shocks were so sudden and so violent that the effects were much greater than in any other part of Luzon which we have visited. We will only mention the damages which masonry buildings suffered: the church of San Ysidro, which although without a roof fell so quickly as to bury in its ruins a child who was passing near it; the church of San Antonio, the front of which fell down, and the tower of which, built of small rounded stones laid in cement, the best kind of masonry perhaps, was thrown down even to the base; and many other masonry buildings which were more or less damaged. We think it will be of interest to describe two cases more in detail; the first is that of a deep well, having a lining built of the best masonry with a foundation of concrete, in the suburb of Sampang near a distillery which was supplied from it. The violence of the shocks lowered the ground on which the distillery stood about one metre, without greatly disturbing the machinery in it; while the well, which was full of water, was left dry and partly filled with sand, and the masonry curbing, either on account of its different density with reference to the soil, or for some other cause which it is difficult to discover, was left projecting some distance above the surface of the ground. The second case, which seems to us the most notable of any observed in the whole extent of territory affected by the earthquake, was that of the church in the little village of Jaen, this edifice had been recently constructed, and con-

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sisted of great upright timbers 14 varas high, 2 varas of this length being sunk into the ground, united at the tops by joists; and on this framework a light roof of wood, cane and "nipa". The building was 60 varas long and 18 wide, and the lateral partitions were of nipa. This structure which would be considered extremely strong against earthquakes, fell to the ground in a most unexpected way. It was thrown vertically to such a height that the upright posts were drawn out of their beds in the ground with scarcely any injury, and then the whole building fell together. A single one of the uprights, which was more strongly attached to the foundation than the others, was not drawn out of the ground, and although it had a diameter of 40 centimetres, it was broken off like a cane at its base, a few fragments of the building remaining attached to the fibres which were not torn away.

In 1871 we inspected for the same purpose some houses in Cottabato, and in 1879 others in a village near to Surigao; these houses were built of wood and nipa and had been thrown down by earthquakes, but they had fallen because the posts by rocking in all directions had opened the framework at the top until the inclination of the timbers was so great that the building fell by its own weight. It is impossible to invent a a method of building which will be proof against shocks which throw structures two varas high, and draw the posts out of their resting-places in the ground without greatly disturbing the soil. From facts procured on the spot, we have succeeded in restoring the building as it was at the instant of its fall, in order that a clearer idea may be formed of the wonderful power of the earthquake.

In the mountains East of the province, in the jurisdiction of Bongabon, there were cases in which rocks on the sides of chasms were thrown down, but we were unable to examine them because during our stay the roads were impassible. We will say however on the word of the Curate of San Ysidro, that in the chasm of Lupingan, the banks formed of hanging rocks were thrown down in to the bed of a stream, stopping the water for two days, at the end of which time the water, having risen and its pressure being greatly increased, forced its way through

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and caused a sudden inundation to the agreeable surprise of the people of the region who were sorrow-stricken at the sight of the dry river-bed.

Bulacan.

This province like that of Nueva Ecija is traversed by a great river, which rising in the mountains which separate Bulacan and the district of La Infanta passes from East to West and runs into the Rio Grande de la Pampanga, which empties by numerous months into the bay of Manila. In spite of the similarity of topography of these two provinces, and although the intensity of the earthquakes was about the same in both, yet the region of the Bulacan river did not present the disastrous effects which were described in speaking of the region of the river of Nueva Ecija. The difference arose, we believe, from the difference of the geological characters of the soil; in the latter the soil is composed, as we have said, of thick layers of modern alluvium, which are without consistency, and hence subject to disturbances of the surface, and consequently to the fissures which we have described; on the contrary in Bulacan the soil is composed of very deep strata of a volcanic stone which is strong and elastic, in which changes of level, fissures, and land-slides are impossible.

This great volcanic formation, of whose origin and wide extent we shall at some future time speak more fully than is here possible, when it was formed, raised the level of this province, leaving the streams running in deep channels as may to-day be observed, and crowding in the banks of the river, which are very steep throughout the volcanic formation. To this last fact it is to be attributed that this province is so free from inundations, and that the recent alluvium posterior to the volcanic formation is only of a very insignificant thickness and very uniform, as it has been for long periods of time free from the action of the water which is usually at a level below the alluvium. As a confirmation of this hypothesis we can cite the low and littoral region of this province, whose surface is almost down to the sea level, and which is composed of recent alluvia in which there have been observed phenomena

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analogous to those of Nueva Ecija, that is, fissures and elevations and depressions of the surface. In the low region just mentioned is the town of Hagonoy, where the earthquakes were felt with extrême violence, and gave rise to depressions and inundations which caused the destruction of houses built of wood and "nipa," and to the opening of fissures two metres wide from which poured forth water and sand in abundance.

We have then in this province two distinct regions in which to study the action of earthquakes; the region of the volcanic formation, which includes the central portion of the province, and the low and littoral portion. In both regions the damages to masonry buildings have been great, perhaps somewhat greater in the low towns than in the high ones; thus, for example, the church and the elegant modern tower of the capital town were destroyed completely, while in Balinag, San Rafael, Angat, and other places on the high land, all the buildings remained standing, although somewhat injured.

In the high region structures in cities suffered, while the ground and structures in the country remained intact; while in the low region structures both in the city and country have been considerably damaged. Neither in this province nor in the others which we have studied were the earthquakes of the afternoon and night of the 20th felt with great violence, although in Manila which is very near they were extremely violent. It is to be noted that the intensity in the different towns of Bulacan was inversely proportioned to the distance from Manila.

After these general remarks on the effects observed in this province, we do not consider it necessary to give details on the different towns which we have travelled through, as they teach nothing new, only confirming the general law which we have given as to intensities and directions of movements, to which there is not a single exception in this province. We will cite a single geological phenomenon which may almost always be seen at time of great earthquakes. There is in a suburb of the village of San Miguel de Mayumo, called Sibul, a large spring; the water is charged with sulphur and iron; and this spring has of late years acquired importance, not only on account of

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its medicinal properties, but on account of the beauty of its situation. The spring pours out from under a layer of limestone, and has formed around the orifice a little basin about a metre deep with a corresponding outlet. At the time of the earthquake, this spring completely dried up and it was only after some hours, which had been probably necessary to overcome the obstacles which were thrown down by subterranean disturbances, that the water, which was much more turbid than usual, returned.

Province of Manila.

Although this province is of very small area, it presents points of observation where the intensity of the earthquakes was very different. The earthquakes of the 18th and 20th of July were everywhere very strongly felt; but, comparing carefully the effects experienced in the different towns of the province, it can be divided into two zones which were differently affected; one from the Pasig river toward the North, in which the shock of the 18th produced all or the greater part of the damages, which were but very little increased by the shock of the 20th; the other from the river Pasig toward the South, in which the first earthquake having produced the same effects as in the remainder of the province, the two shocks of the 20th considerably added to the damage, and caused others besides, throwing down structures which had resisted the first shock. We do not seek to carry our theory so far as to consider the Pasig as the mathematical dividing line of the two zones; for this would be thought by many to be a scientific refinement, a mathematical nicety, which we ought to avoid when treating of nature, which in its grand march is not accustomed to submit itself to the petty and too frequently unvaried rigor of science. But it is really worthy of observation, even though it be accidental, that the villages situated on the left bank of the Pasig were damaged much more in the earthquakes of the 20th than those on the right bank. In Manila even, with numerous buildings on both banks of the river, it was noticed that the large structures (churches and towers) suffered more on the left bank than on the right; thus the towers of the

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cathedral and of San Agustin, and the cupolas of San Francisco and Recoletos were thrown down almost completely on the 20th; while in the suburbs on the right bank all remained standing without any important damage, the towers of Santa Cruz, Quiapo, Binondo and San Sebastian, all high and of no better construction than those in Manila.

With regard to the other villages in the province, it was observed that in those to the North of the Pasig river, such as Malabon, Navotas, Caloocan, Mariquina, Cainta, and even Pasig on the bank of the river, the destruction was not complete except in the case of masonry buildings in a more or less ruinous condition; while in those to the South of that river, as Paco, Santa Ana, Guadalupe, Pateros, Parañaque, Las Pinas, etc., the damages were more important, in some cases amounting to complete destruction, as in the solid sanctuary of Guadalupe, an ancient structure which had withstood the shocks of the last three centuries without injury, and which, having remained standing through the earthquake of the 18th, was completely destroyed by the falling of its arched roof of masonry on the 20th.

Province of La Laguna and District of Morong.

Les us group these two provinces together, as they include the whole perimeter of the great lake Bay, in which the earthquakes of July present such variations that their study is very complicated, and it is very difficult to deduce general consequences which give a more or less exact idea of the phenomena during the three days, the 14th, 18th, and 20th of July, in which they manifested themselves.

We observe, in the first place, that while the first earthquake of the series, that of the night of the 14th, left no traces of its action in the localities which we have so far studied, and would have had no importance had it not been followed by other greater ones, in the region which we are about to investigate at some points it had a much greater intensity and a much longer duration, and caused considerable damage.

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Passing around the lake from Taguig towards the South following the West coast, all the reports which we obtained and the effects which we observed demonstrated that the first earthquake had had no importance in Muntinlupa, Tunasan, Biñan and other places as far as Santa Cruz. In the last place it could be seen that the effects produced by it were much greater than had been observed up to that point; for example, the fall of brick partition walls, and numerous cracks in stone walls of coursed masonry.

In the other towns on the East coast as Longos, Paete, Panguil, Siniloan, etc. and in the corresponding ones in the district of Morong as far as Pililla, we obtained reports of that earthquake, and we were shown marks of seismic action which revealed a greater intensity even than in Santa Cruz; in the village of Pililla the force was so great as to open wide cracks in the church and tower, and throw down one of the few masonry houses which exist in this place. Leaving this village toward the West, the intensity of that earthquake seems to have been constantly less and less until we reach the province of Manila, in which we have already described the phenomena.

The earthquake of the 18th was felt very heavily in both provinces; it is to be noted however that on the Western coast from Taguig to Bay the intensity was somewhat less than on the opposite side of the lake. Thus, the towns Biñan, with many masonry structures, Santa Rosa, Calamba and Los Baños felt the earthquake without any damage; while in the towns on the Eastern coast from Santa Cruz to Santa Maria the masonry structures were mostly laid in ruins.

The earthquake of the 20th, on the contrary, acted with greater violence on the Western coast than in the other parts of the two provinces, and had in some villages greater intensity but less duration than that of the 18th. In confirmation of this statement we will give the following well-known fact. As soon as the people of Biñan knew that Santa Cruz, the capital of the province, had been destroyed by the earthquake of the 18th, while the buildings in their town had escaped injury, they loaded a number of boats with materials and men and went to aid the people of the capital. When they were

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returning on the 20th and were about to run into their own port, the earthquake of 3 P. M. took place, and was felt in the boats with extraordinary violence; and when they landed they found their principal buildings demolished. The earthquake which occured that night finished the work of destruction. We had occasion to make another noteworthy observation in travelling along the Southern coast of the lake, in the villages of Calamba, Los Baños and Bay, situated almost on the slope of the great volcanic mountain called Maquiling. In these three villages so near to the volcano whose influence in the earthquake had been so much exaggerated in Manila, we were agreeably surprised to see only the slightest damages compared with the localities visited before and after this small volcanic region.

The observation of this reduction of intensity led us to believe that the great volcanic mass of Maquiling, the first of the chain of mountains which separate this province from Batangas and Tayabas, served as a barrier to the seismic vibrations, and reduced their intensity, which according to what was observed later was very much less in the Southern provinces.

District of La Infanta.

Three days journey from the village of Siniluan in the province of La Laguna through high and wild mountains, brought us to Binangonan de Lampon, the only village in this province on the island of Luzon. The island of Polillo, containing a village of the same name, is a part of this district.

From the reports which we were able to obtain and the effects observed, we conclude that the earthquakes were extremely severe in this locality, although not so severe as was represented by the public press of Manila, which derived its information from some natives from the Pacific coast through intelligent and well-meaning persons in the province of Laguna.

A certain journal went so far as to suppose that a volcano had appeared on the Pacific coast, and spoke of the formation of new mountains and the disappearance of old ones, of great gaseous and liquid discharges, of a great number of boats cast

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up on the shores to a great height above the sea, and even of the disappearance of hundreds of human beings. The greater part of these statements were false and the remainder exaggerated as we shall see.

At about the same time as in Manila in the night of July 14th occurred the first earthquake, which was much more intense here than in Manila. In fact the people of Binangonan assert that this earthquake was the most severe one felt since 1863. Before 9 o'clock on the morning of the 15th the shock was repeated nine times. During the 15th, 16th, 17th, and 18th of the month so frequent were the repetitions that, as many people have assured us, not an hour passed without a shock, and the greater part of them were preceeded by subterranean noises.

A little after midday on the 18th the great earthquake happened, which caused all the injury to buildings and all the disturbances to the ground, of which we shall speak hereafter.

From this time the ground was still until the 20th, when four more shocks were felt during the afternoon and night; it was impossible for us to ascertain the exact times of the earthquakes, but it is reasonable to suppose that they were the same as in Manila. The intensity of the shocks of the 20th was by common report very much less than that of the shock of the 18th.

On the following days slight shocks were frequently felt, but they grew weaker and finally ceased. The governor of the district informed us that in the island of Polillo only the earthquake of the 18th was felt, and that it only caused a very little damage to the church. We were not able to visit the island because at the season of our arrival at La Infanta (22d of December) it is impossible to make the passage from any point without great danger of shipwreck.

The effects produced in the buildings of Binangonan by the earthquake of the 18th were the following:—The church, the tower and the convent, the only masonry buildings in the village, which we were informed were not in good condition, fell to the ground. The church had walls of plaster and a roof of nipa. The tower was all built of plaster, and the convent was built of plaster with a tile roof. The destruction

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was complete, especially of the tower, whose foundations were so moved as to disturb the ground which surrounded them.

The government house, the court-house, the barracks, all built of wood and nipa, were so badly injured as to be uninhabitable, and they were so much inclined that the latter finally fell down. More than two hundred houses built of wood and nipa were ruined by the great disturbances of the surface of the ground; some fell down leaving the vertical posts standing loosely in their beds, which had been enlarged by the oscillations.

The disturbances of the ground were, so far as we could see, small in the neighborhood of the village; but they were very considerable at two points on the shore of Puerto Real de Lampon, and in the mountains which separate this district from that of Morong and the province of Bulacan. Close by the village there were only a few fissures of little length near to a stream called Sapa, which runs in a deep bed through a meadow on the North-eastern side of the town, and a little more than a kilometre distant from it. The hanging clay banks of this stream fell down in several places dragging with them the vegetation; and in one place where the bed was very narrow (scarcely two metres wide) the caving-in obstructed the current so that the meadow was partly inundated for a few hours, until the obstruction was washed away.

The other place was about half-an-hour's journey in a South-westerly direction from the town; here fissures were formed of a greater length than those just mentioned, but of very small width, which poured out water and mud. The same thing happened on the shore of Santa Monica and in some other places around the town, but in all these cases the phenomena were on so small a scale as to be hardly worth mention.

In the mountains of the dividing chain of the island, on the West and North-west of Binangonan the effects were very important, producing numerous and great land slides on the steep Eastern slope, which were formerly covered by thick vegetation, and leaving great tracts completely bare. Five months afterwards although the vegetation is very vigorous,

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we could count more than sixty of these bare places in the single mountain called Binnan at about six leagues to the North-west of Binangonan. The few inhabitants in the mountains (for the most part natives, negritos,) hurried down to the plains in all haste, terrified at phenomena which made such frightful noises and made the earth vibrate so continuously.

On the coast of the Puerto Real de Lampon, four miles (Spanish) from Binangonan, there are important depressions, one at Point Tacligan and another at a place called Quinanliman. The sketch given herewith shows exactly the situation of these two places.

At Point Tacligan the depression of the land increased from A and C towards B; at the last point, where formerly the land was some decimetres above the surface of the water, the water was six metres deep; while at A and C, the ground was lowered only so much that the vegetation, which was very thick at this place, was killed by the action of the salt water on its roots. At B the dead tops of the submerged trees were visible. It appears as if the whole tongue of land had revolved about an axis approximately parallel to the line AC.

At Quinanliman the depression had a wide extent, but was very irregular in depth: the greatest depth was four metres at the centre line DE of the submerged surface; and from this line in both directions the depth gradually diminished.

A suburb called San Rafael had been formed in this locality a short time before the earthquakes, to take advantage of the good forming land. This suburb was submerged the 18th of July, and was abandoned without loss of life. It is probably this incident which gave rise to the story in Manila that hundreds of human beings had disappeared.

With regard to the story of the boats which had been cast up on the shore to a great height above the sea, we could not find any confirmation of it; even the fishermen in Puerto Real were astonished when we told them of it. The only accident which offers any explanation of such exaggeration is that some small boats which had been out in the estuary which opens into this port, were thrown by the inundating waters up

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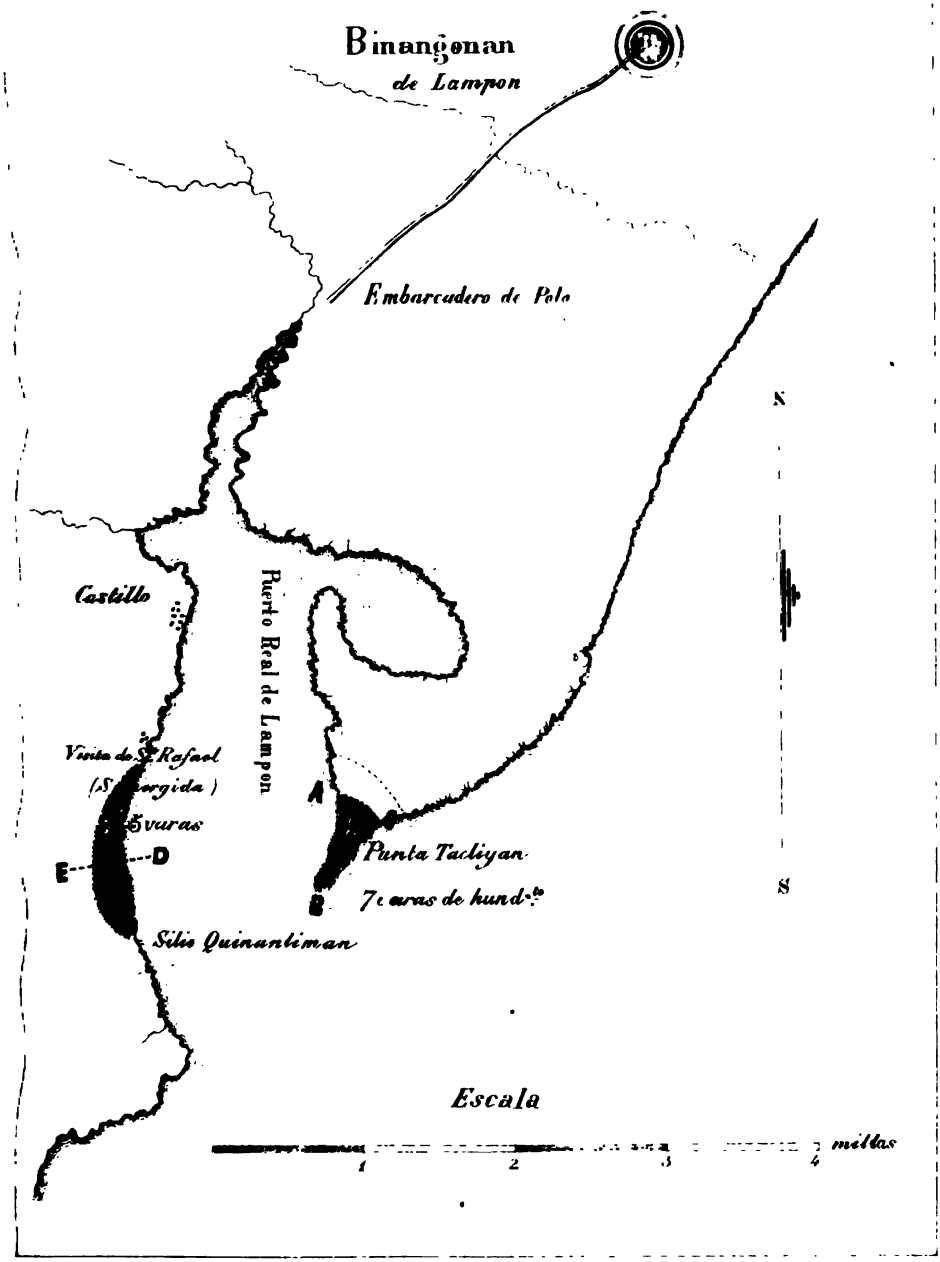

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into the mangrove thickets which line the shores of the estuary, and were left dry when the water returned to its level.

Province of Cavite.

The effects produced in this province were almost as great as those in the contiguous parts of the province of Manila. The shocks were felt with equal violence and in equal number, although it was observed that the intensity was gradually less from North-east to North-west.

We will not enter into details concerning the action of the earthquakes; it will be sufficient to say that some buildings were more or less injured, while the ground showed no marks of violence except some small cracks at points near the shore, as at Cañacao, where several were opened which poured out water and sand.

III

Effects observed in the Southern Provinces.

Batangas.

It was with great anticipations that we went to examine this typical volcanic province, thinking to find more notable marks of the earthquakes of July in its soil than in any of the provinces already travelled over. The reports, sometimes terrifying and sometimes reassuring, which were received in Manila concerning the volcano of Taal and mount Maquiling, which were then considered the arbiters of our fate; the telegrams, as laconic as alarming, which represented these mountains to be first in full eruption and then perfectly quiet; those urgent warnings, advising the precautions to be observed on account of the suspicions state of the volcano; all these reports, these prophetic warnings, which were in no way confirmed, excited our desire to visit this province, which we expected to find completely disorganized by the earthquakes of July. What was our surprise to find that if those volcanoes had had any influence on the effects of the earthquakes, it was a markedly beneficial one.

Neither the crater of Taal nor the boiling springs on the South-western side of Maquiling, which we examined carefully,

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showed any marks of recent change, much less of such cataclysms as young and enthusiastic imaginations had thought they saw. According to the reports which we obtained in the locality, when people had become somewhat reassured, it seems that not only did no new volcano appear, (a supposition which might have arisen from one of the beautiful tropical sunsets or from mistaking some other peak) but that the old ones showed no abnormal activity, indeed not as much as they often do when unaccompanied with earthquakes.

We entered this province from the town of Calamba in La Laguna, and passed successively through the towns of Santo Tomas, Tananang, and Talisay, Taal, Banang, Batangas, San Jose, and Lipa; returning to Santo Tomas, we took the road to San Pablo and afterwards proceeded to Tayabas. We stopped in Santo Tomas especially to investigate the hot springs of Mount Maquiling, and again in Talisay as the nearest point from which to visit the little island which was formed by the volcano of Taal in the middle of lake Bombong.

In none of the villages passed through did we observe any effects of the earthquakes, either in the ground or the buildings. In Santo Tomas, the village nearest to the province of La Laguna, the church was considerably damaged, but this was due to faulty construction rather than to the action of the earthquake; as the convent next to the church, which was built of masonry and covered with tiles was so little injured that it was, without repairs, continually occupied. In the town of Lipa, where there were numerous edifices of masonry covered with tiles, and higher than we have seen elsewhere in the Philippines*, there was not the slightest injury; even in the five-story tower of the church there was not a visible crack.

The same earthquakes were felt as in Manila; but the greater part of the reports received agree in assigning the greatest importance to the shock of the 18th, and placing the anterior and posterior ones much lower in the scale of intensity.

The statements which we could make concerning the effects in this locality would be mainly negative; it will suffice

* There are some buildings having a ground floor and three other stories, all covered with a tile roof.

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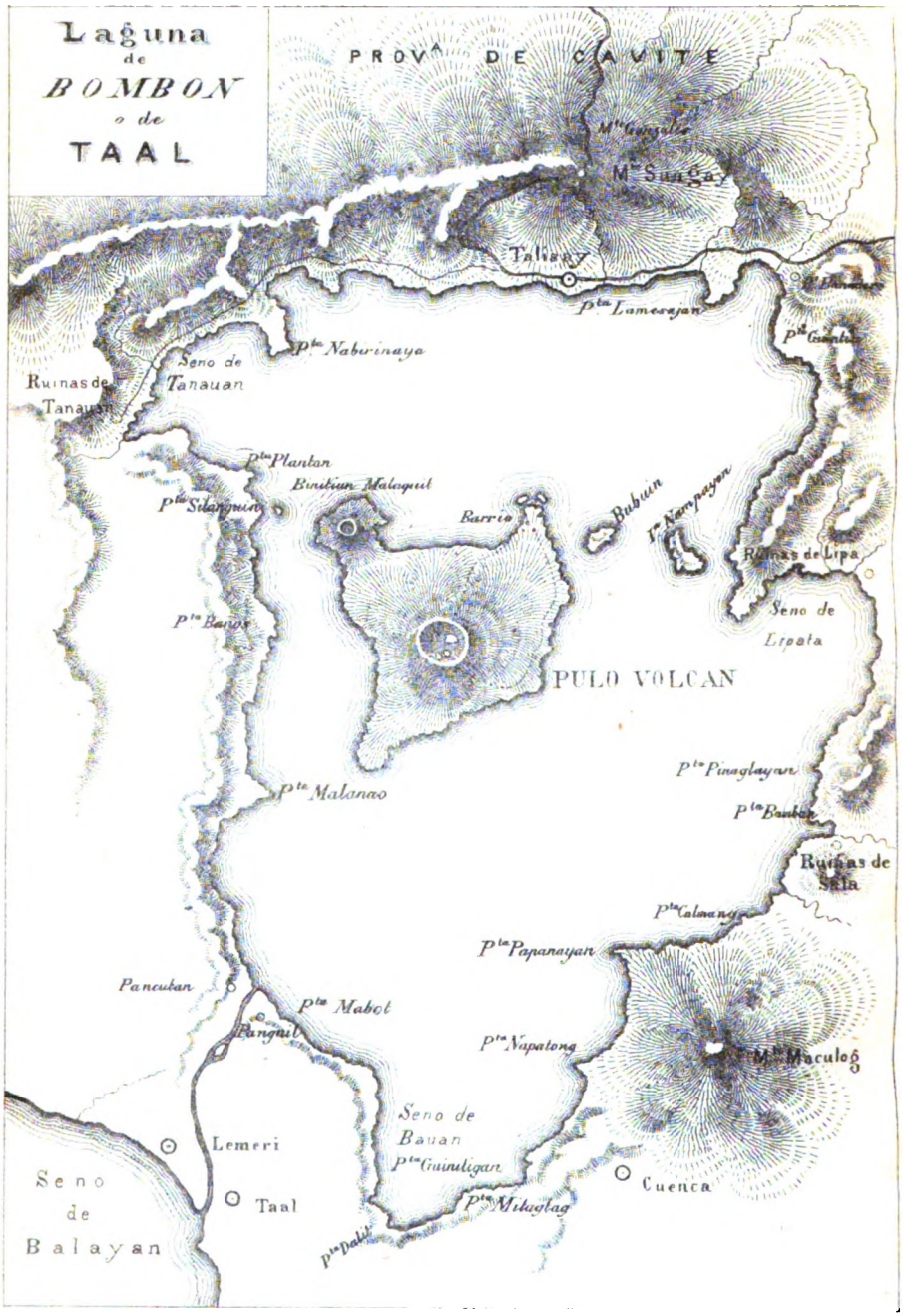

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to say that, with the exception of the village of Santo Tomas, none of the churches of this province, including the very high one of Taal, nor of the great masonry structures which are numerous in many of the villages, suffered noteworthy damage, the small damage experienced amounting to a few cracks which did not affect the stability.

Here we ought to terminate what we have to say concerning the earthquakes of July in this province; but considering that, among the theories which have been advanced by eminent men in all times relating to such phenomena, there is one theory which attributes them to volcanic action, we can not let such an inviting opportunity pass by to study an active volcano in the midst of a zone lately disturbed by heavy earthquakes, as well as to say a few words on that igneous center and the scientific paper which was intended to show a connection between this volcano and past seismic events.

The sketch herewith shows the situation in the lake of Bombong of the island called Puló Volcan in whose top there is now a crater, as well as the situation of the other small islands in the same lake, all of which are volcanic and have been active in historic times. The islands of Bubuin and Nampayon appeared in 1716, forming then a single island, and the principal crater was then in an island known as Subugnapuls which disappeared in the eruption of that year, although its base may still be seen near the island Puló Volcan.

The greatest length of the island of the volcano is from North-east to South-west and is about five miles (Spanish), and the height of the edge of the crater is on the South-eastern side 190 metres, and on the Northern side 275 metres. The general form of the edge of the crater is approximately oval, (Fig. 3) with its major axis 2600 metres long. The interior surface is that of an inverted truncated cone, whose height is approximately that of the edge of the crater above the water of the lake, and whose smaller base is the bottom of the crater. There are several small cones on the floor of the crater of which only one is active, and this one throws out great quantities of vapor. There are also two boiling lakes, with metallic oxides and salts in solution, which color the smaller one a pure emerald

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green, and the larger one a reddish yellow.

In the larger lake every few hours the center is blown up like an immense bubble, which rises one, two, or three metres above the surface and finally bursts, revealing a black orifice and making the boiling water appear all imaginable colors.

It is impossible for us to describe the beauties of the crater, whose bottom and interior walls, accessible at various points, present such varied structures and colors, from the black and compact basalts to the fragile, spongy, and almost transparent modern scoriae. The most finished description would not give even an approximate idea of that grand amphitheater, where every stone has its history, having been thrown thousands of times up to great heights, and having been dissolved and deposited until there are multitudes of transparent and colored crystals. In the sketch which has been given, the relative situation of the various parts of the crater may be seen.

The changes which this volcano has undergone and the disasters which it has caused since historical times are very remarkable. According to the chronicles of the time of the conquest, the crater was then on the South-western point of the island of Puló Volcan, having a cone which exists today and is called Binintian-Malaquit. A few years after the conquest that crater ceased acting, and another appeared on the Eastern side of the island, which in 1716 was submerged, leaving above the surface the two islands Bubuin and Nampayon. Then a new crater appeared on the Eastern side of Puló Volcan, which was gradually enlarged toward the West until the present crater was formed, which has not varied much since 1754. Among the various eruptions since the conquest, the most notable are that of 1749 where the village of Salá disappeared, and that of 1754, the greatest of all, when the villages of Taal, Lipa, and Tananang which were then on the shores of lake Bombong all disappeared. All the eruptions have consisted of showers of burning ashes and scoriae, between which showers great blocks of basalt were thrown out, covering the whole region to a depth varying from a few centimetres to two or three metres, and causing the different strata of volcanic material which can be seen throughout the province. We know of no observations

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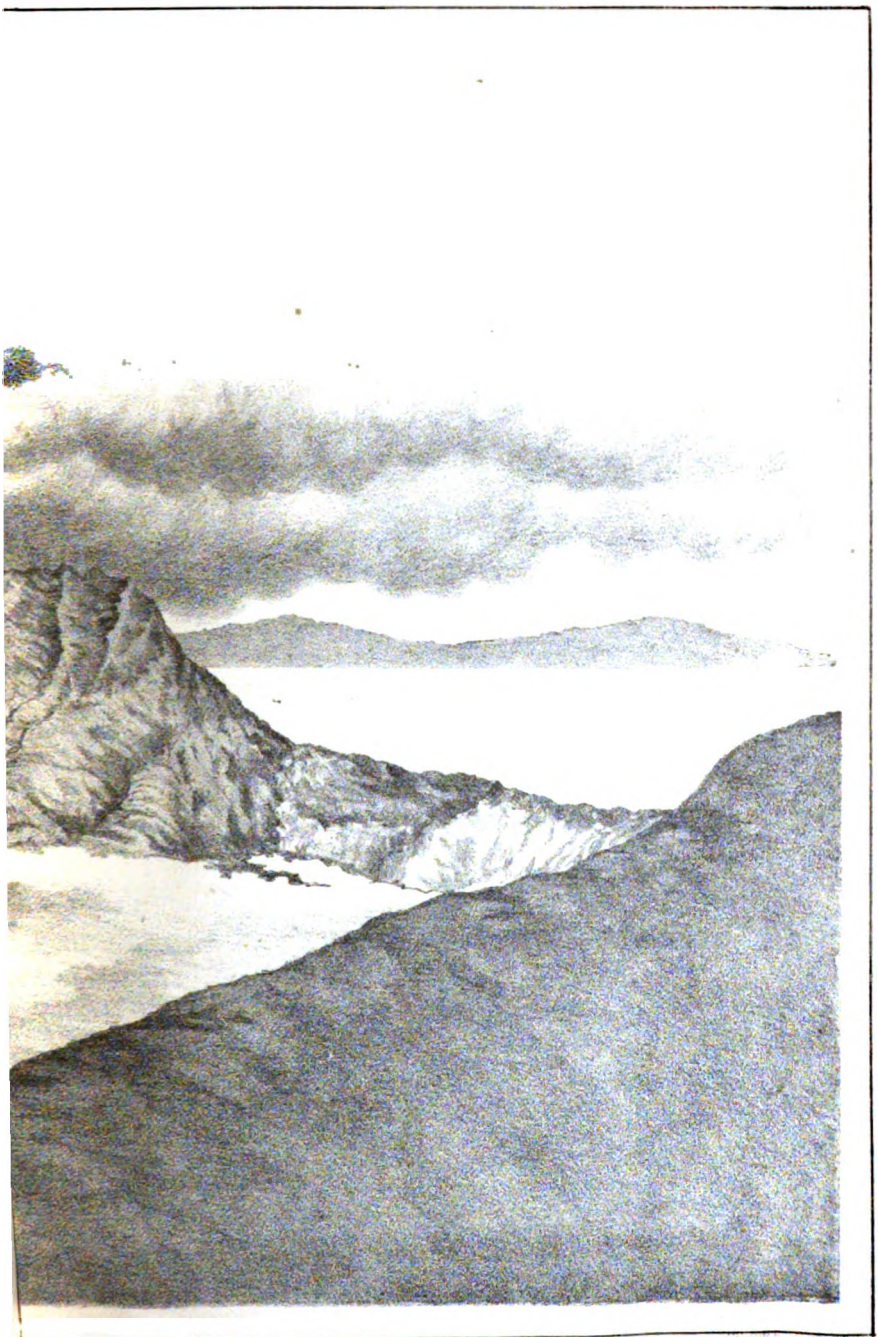

IORTE DEL MISMO

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which would show the relation of earthquakes to the eruptions up to 1874; but since that date we are able to give a few, which, as well as some of the facts already stated, we owe to the kindness of the curate of Talisay, Father Celestino Redondo.

On the 17th of May 1874 there was an eruption of black smoke and ashes unaccompanied by an earthquake.

On the 19th of July in the same year there was an eruption of gases, which were so sulphurous that the characteristic odor was perceptible as far as the town of Talisay. A great herd of cattle died on the island of Puló Volcan, on whose Western shore there was abundant vegetation which was mostly burned up. There was however no earthquake.

On the 24th of June 1877 from one until half past six in the morning, seven heavy earthquakes were felt, which were violent enough to cause cracks in the wall of a convent. These earthquakes were felt in Silan in the province of Cavite, but in many villages of Batangas they were not observed. They were not followed by any eruption.

From the last of October 1878 until the 12th of November, subterranean noises were heard frequently in the direction of the volcano. On the day mentioned an eruption began which lasted until the 15th and covered the whole island of Puló with a shallow layer of volcanic ash; there was however no earthquake.

Finally from the 8th of June 1880 the volcano was observed to be more active than usual, and some nights the crater was covered with a glare; and on the 17th, 18th, 19th, 20th, and 21st of July subterranean noises were heard and from time to time a small ball of fire (about half a metre in diameter) appeared above the crater; these balls burst at quite a height into small fragments a part of which fell back into the crater and the remainder upon the exterior slopes.

We might say much more of this volcano whose sphere of action in geological times must have been much greater than in historical times; perhaps then the lake of Bombong was the crater. But this would carry us too far from our present purpose, so we repress our desire until a more opportune occasion.

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Province of Tayabas.

We travelled through this province setting out from Santo Tomas in Batangas and going in the direction of San Pablo; and we then passed through the villages Dolores, Tiaon, Sariaya, Candelaria, Tayabas, and Lueban all situated on the slopes of the two great volcanic promontories called Majaijai and Banajao.

From Lueban we passed over to the Pacific coast, which is a continuation toward the South-east of the coast of La Infanta, and inspected the towns of Mauban and Atimonan; crossing lastly the narrow isthmus which separates the Pacific Ocean from the sea of Mindoro, we arrived at Laguimanoc, whence we set out for Camarines.

During this journey we observed that the intensity of the July earthquakes decreased from the Pacific coast towards the West. In the towns named, with the exception of Mauban and Atimonan, we did not observe any important effects either in the buildings or ground, the only damages being slight cracks which did not render the buildings uninhabitable. In a single convent, that of Tiaon, which for some time past had not been occupied on account of its dilapidated condition, a part of the roof fell in; the church which was near the convent was also in a bad condition, but it resisted the action of the earthquake and continued to be used. Neither in Tayabas, nor in Lueban, nor in Sariaya where, besides the church and convent, there are many other masonry buildings with tile roofs, were left any marks of seismic action from the earthquakes of July, which were however felt in as great numbers as in Manila, although with much less intensity.

We will only give a few effects which were observed in Mauban and Atimonan on the Pacific coast, where the phenomenon assumed some importance.

Provinces of Camarines and Albay.

Although this description may appear long, we have thought it necessary to go into details, so that the reader could form his own opinions on the course of the phenomena, independently of our ideas. To bring the account to an end,

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we will add a few words about the two provinces named above, in which there was a great diminution in intensity in proportion as the earthquakes had travelled toward the South-east; so that at the extremity of Luzon, near the straits of San Bernardino, there are places where the earthquakes of July passed unobserved.

In North and South Camarines the shocks had considerable intensity in all the villages in the North-eastern parts, but did not however injure any buildings or cause any marked disturbances of the ground. In Nueva Caceres, the capital of South Camarines, where there are many masonry buildings some of which are of great size, as the government house, the bishop's palace, churches with high towers, &c., we were shown as the greatest damage which was caused in that place a small crack in one of the walls of the government house. This crack was even smaller before the local earthquakes of the volcanic region of Mayon, which were felt here in last November, and which opened the crack somewhat. In the other places to the South-east of Nueva Caceres as far as Albay, the intensity was even less. The earthquakes seem to have been entirely extinguished in the line of volcanoes which begins with one called Ysaró and ends with Bulusan, and includes those called Yriga, Masaraga, Bulic and Mayon, the last of which has a height of 8000 ft., and has concentrated in itself all the volcanic activity of the whole region. All this locality is frequently disturbed by local earthquakes which do not generally pass out of South Camarines, and ordinarily are preceeded by some eruption, or at least some notable variation in the activity of the volcano.

IV

General Deductions.

If, in some of the places examined in the different latitudes of Luzon, the earthquakes had been registered with accuracy, as they were in Manila, by seismometers, nothing would have been easier than to have traced on the maps the lines which mark the zones of relative intensity; but, lacking these observations, and obliged to estimate the direction and force of the motions by the effects which they produced in each locality,

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we have great difficulty in presenting the deductions which indicate generally the character of the phenomena. We shall do it however because, besides fulfilling our obligations, our opinions will leave the reader completely free to form his own ideas; and from the minute and trustworthy observations which we have here recorded he can test or modify the deductions which we make.

We first call attention to this fact, that all the earthquakes from the 14th to the 25th of July can be divided into three classes corresponding respectively to the 14th, 18th and 20th days; and that each of these classes has its own special zone of maximum intensity. The first, which includes all the earthquakes which occurred between the 14th and the 18th, had its greatest intensity on that part of the Pacific coast which corresponds to the district of La Infanta and the province of Tayabas, and on that part of the shore of lake Bay between Santa Cruz and Morong. Leaving this region of maximum intensity, which we have marked on the map with a red line, the intensity became less and less until in Pangasinan in the North, and Camarines in the South, the earthquakes in many towns were not noticed.

The second class, which on account of its great intensity and extent is the most important of all, had its maximum intensity in the territory included between the Western coast of Tayabas and La Infanta and the most Western spurs of the mountain-chain which beginning at Baler runs towards the South and ends in the volcanic mountains of Tayabas near the narrow isthums of Atimonan. The seismic waves in this great shock had much greater extent and intensity toward the North-west than toward the South-east; in the first direction including all the island of Luzon and probably part of the China Sea between Luzon and Formosa, while in a South-easterly direction the seismic action was entirely extinguished before reaching the Straits of San Bernardino, so that the loss of intensity must have been much more rapid. It can be calculated that the surface more or less violently disturbed by the earthquake of July 18th, deducting the part on the ocean as we have no exact observations as to its boundaries, was

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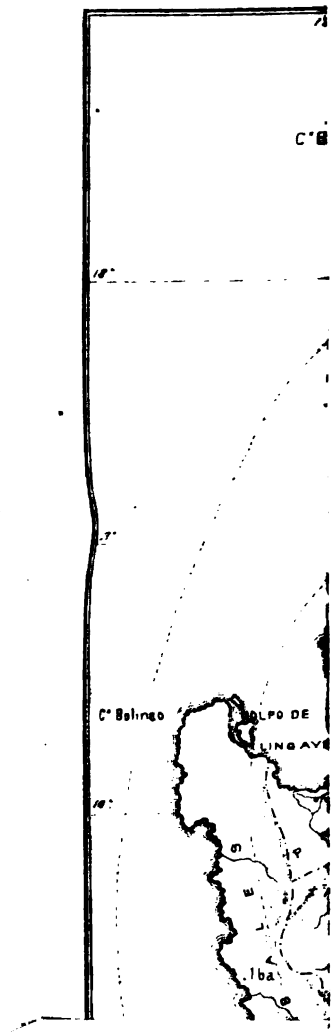

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about 357 square leagues.* On the map we have drawn black lines to show the different places at which the intensity was the same. According to observations made in our journey the region of maximum intensity was in Nueva Ecija, the mountains of Bulacan and Morong, the district of La Infanta and a part of the province of La Laguna, all of which territory is included in the inside curve.

In the determination of the curves which limit the successive zones, we have endeavored to draw them so that they include all the points at which the effects observed, by careful estimate, were about the same, rather than to make them represent the course of the seismic waves; it would have been impossible for us to do the latter, as we had no more exact observations than could be obtained from ruined buildings and disturbances of the ground.

Finally the third group, which includes all the earthquakes which happened on and after the 20th, presents a very small zone of maximum intensity, in spreading from which the motion decreased so rapidly that while the greatest action was on the Western shore of Lake Bay, or perhaps in Manila, in the adjoining provinces toward the North and the South, that is in Pampanga, Nueva Ecija, Batangas and Tayabas, that shock was hardly distinguished from the other slight shocks which were felt from the 18th to the 25th of July. On the map we have drawn a yellow line including a small part of Lake Bay and a short stretch of its Western coast, the peninsula of Jalajala and the island of Talim; and this line incloses the region of maximum intensity, where the action of these earthquakes was much greater than in the other parts of the province of Manila, and where they were especially violent at points South of the Pasig river. In speaking in detail of this province we have called attention to the singular fact that this Pasig river seems to be a dividing line between two districts in which the intensity of the earthquake of the 20th was very different; this fact is our reason for drawing one of the curves to coincide with this river.

April 1881. JOSÉ CENTENO.

*56000 square miles. [*See note on next page.*]

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NOTE. The figures referred to in the first section of chapter 1, are already known to the Seismological Society of Japan, and for that reason have not been given.

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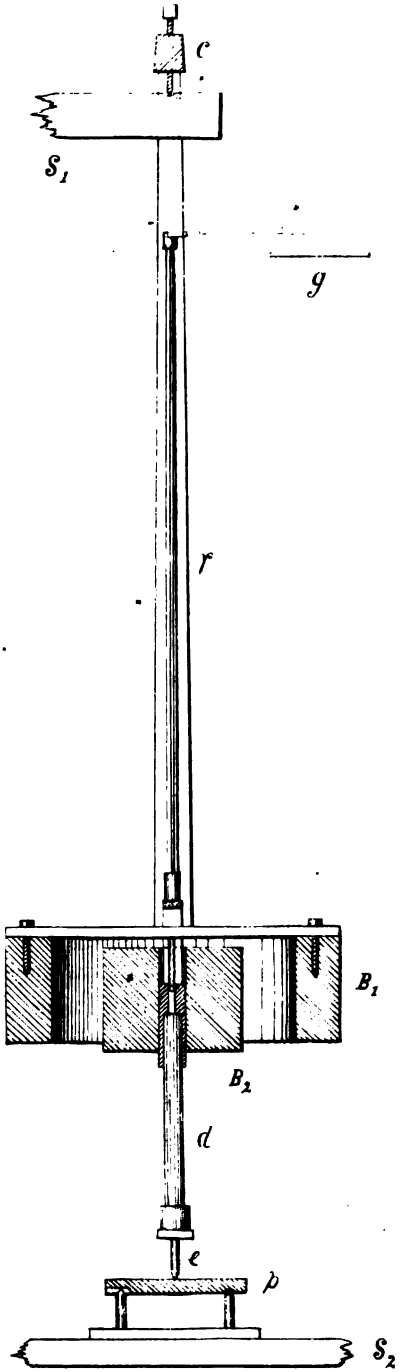

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SEISMOLOGICAL NOTES.

BY

PROF. J. A. EWING.

[READ NOVEMBER 21ST, 1882.]

I. *A Duplex Pendulum Seismometer.*

The fault of the common pendulum when used as a seismometer is its too great stability. This may be reduced enough to fit the instrument for seismometric work by making the length of the pendulum inordinately great, as was in fact done in the pendulum seismometer which I had the honour to describe to the Society in 1880.* But a very long pendulum presents, in its construction and use, so many difficulties as to be almost impracticable, and methods have been suggested by Mr. Gray † and also by myself ‡ whereby a short pendulum may be brought to a state of neutral or nearly neutral equilibrium. The "Duplex Pendulum" which is now exhibited to the society achieves this result in an entirely new way.

Briefly the idea of the new instrument is this. The common pendulum is stable: an inverted pendulum with pivotted supporting rod is unstable: by placing an inverted pendulum below a common one and connecting the bobs so that any horizontal displacement must be common to both we may make the equilibrium of the jointed system neutral or as feebly stable as may be desired.

The figure shows a vertical section through the instrument. B_1 is the bob of the upper or common pendulum consisting of a hollow cylinder of lead, which is hung by two light wooden rods from a cross piece c in which a steel pin is

* *Trans. Seis. Soc. Jap. Vol. I. p. 38.*

† *Trans. Seis. Soc. Jap. Vol. III. p. 145.*

‡ *Ibid. p. 147.*

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fixed which stands in a conical cup of agate in the fixed support S_1. This gives the pendulum freedom to oscillate in any azimuth. B_2 is the bob of the lower or inverted pendulum. It is fixed to a stout circular rod d which is pivotted to a second fixed support or base S_2 by a somewhat peculiar joint. Two feet e fixed to the rod of the inverted pendulum stand respectively in a conical hole and V slot on the upper surface of a steel plate p, on the lower surface of which there are another conical hole and V slot in a line at right angles to the line of those on the upper surface. Into the lower hole and V a pair of inverted feet fixed to S_2 press up. The upper and lower slots and Vs are arranged so that their vertices are all in the same horizontal plane. This mode of support also gives freedom to oscillate in any azimuth, and it is employed instead of the more simple method of pivotting a single foot in a single conical hole in order that there may be no freedom on the part of the lower pendulum to rotate about a vertical axis. There is therefore no objection to using a prolongation of the lower pendulum as the indicating pointer. The bobs B_1 and B_2 are connected thus: from a rigid brass bar extending across the top of B_1 there depends a rigid vertical projecting piece ending with a spherical ball which just fits in a cylindrical hole in a tube fixed to B_2. The pendulums therefore move freely together, this joint giving them the necessary power of vertical sliding relatively to each other through a small distance.

The spherical ball on B_1 and the tube on B_2 are placed so that their point of contact is at the centre of percussion of both pendulums. This is the *kinetic* condition which must be fulfilled in order that this point should be the "steady point" when a displacement of the earth occurs. The point of contact is of course a short distance below the centre of gravity of B_1 and above that of B_2.

If for brevity we call W_1 and W_2 the weights of the pendulums referred to this point (that is, the actual weight of each multiplied by the distance of its centre of support from its centre of gravity and divided by the distance of its centre of support from the point of contact between the ball and

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tube, then the *static* condition which will give neutral equilibrium in very small displacements is that

$$W_1 l_2 = W_2 l_1$$

where l_1 and l_2 are the lengths of the pendulums measured from their point of contact to their respective points of support. In practice a small margin of stability must be given by making $W_1 l_2$ somewhat greater than $W_2 l_1$.

The indicating pointer consists of a light wooden rod r forming a prolongation of d. At the top of this a light projecting arm is hinged and stands out horizontally with its end (steel-tipped) touching a smoked glass plate g. The ratio of multiplication of the record is the distance from the hinge to the lower pivot divided by l_2.

When its equilibrium is nearly neutral the duplex pendulum forms an exceedingly sensitive level. If the line joining the upper with the lower point of support is not perfectly vertical a very large deflection of the pointer results. It is easy to show mathematically that if the equilibrium were exactly neutral when the line joining the supports is vertical the apparatus would be unstable should any deflection of this line from the vertical take place, and that when there is some small stability the effect of such a deflection is to cause a large displacement of the bobs. The same characteristic is however shared by other neutral or nearly neutral equilibrium seismometers, such as the rolling sphere or the horizontal pendulum.

The instrument now shown to the society has been too recently constructed to allow me to give any account of its performance in an actual earthquake, but when tested by means of a shaky table it appears to work very well.

II. *The Suspension of a Horizontal Pendulum.*

The method of support hitherto adopted in my horizontal lever seismometers has been to use a rigid frame pivotted by joints at two points nearly in the same vertical line. In place of joints we may use flexible connections, since the actual angular displacement is never large, just as in clock pendulums a spring suspension is commonly used in place of a hinged

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joint. Mr. Gray has described a modification of the horizontal lever called by him a conical pendulum seismometer, in which the frame of the lever is reduced to a single strut and tie, the strut being set horizontally with its end jointed to a fixed support and the tie consisting of a wire fixed at its upper end, so that its flexibility and torsional elasticity make it serve as a substitute for a second joint. Recently I have gone a step further, and have introduced a flexible spring or wire in place of the other joint also. To do this it is only necessary to fork the strut and carry it out beyond the vertical axis of support and then tie it back to the axis by a flexible spring, preferably a steel band with its flat side vertical. The wire tie intersects the vertical line through the centre of gravity of the mass at a point horizontally in front of the lower point of support to which a prolongation of the strut at the back is tied by a flat steel band. A fixed pin sliding freely in a slot on the strut is added to prevent any bodily translation of the strut to one side or other during an earthquake, and hence the hanging mass has no other freedom than that of rotation about the nearly vertical line joining the upper and lower points of attachment. So far as can be judged by recent experiments this arrangement offers less frictional resistance than the method of support by pivots, and any change which gives a diminution of friction is an improvement in a seismometer.

III. *A Speed Governor for Seismograph Clocks.*

The fluid friction governor shown to the society on a former occasion possessed the defect that the balls (whose centrifugal displacement caused fans to be immersed more or less deeply in a trough of oil) were liable to be disturbed by an earthquake, so that the action of the governor became to some extent irregular at the very time when uniformity of speed was most necessary. A modified form which has been recently applied to the clock of the seismograph in Tokio University overcomes this difficulty successfully. Instead of two balls two pairs of balls are used, fixed at the ends of links which cross the spindle X-wise. The upper ends of the links

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also carry the fans whose immersion in oil checks the speed. A pair of springs resists the centrifugal tendency of the balls. The centre of gravity of each link with its attached balls coincides with the joint between it and the spindle, and consequently the shaking of the clock during an earthquake produces no change in the configuration of the governor. The effect of an earthquake on the oil in the trough is immaterial, both in this and in the older form.

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NOTES ON THE EARTHQUAKE AT ATAMI, IN THE PROVINCE OF IDZU, ON SEPTEMBER 29, 1882.

BY

T. DAN, S.B.

[READ NOV. 21ST 1882.]

On the morning of Sept. 29, a severe and sudden shock of earthquake was felt at Atami, causing much alarm to the people and leaving after it, as the effect of its violence, considerable amount of damage in the town and its neighborhood.

Nobody seems to have felt any feebler shocks precede the heavy one, which startled us from our sleep about 5 o'clock or a little before. An intelligent fisherman told me, however, that when he was returning in a boat, in company with another, about the same time from the fishing port of Aziro, about 5 miles south of Atami, he distinctly heard a roaring sound in the mountains and immediately after, felt his boat shaken violently. As the time was early and almost every one was yet asleep, I found no one else to confirm his statement. I am sorry that I could not record a more definite time of the shock, on account of confusion caused by its severity and suddenness. The duration of the shock seemed very short, probably lasting only a few seconds. I felt as if the shock consisted of a series of rapid vertical thrusts. Servants in the house who were up at the time said that they all held on to something for fear of falling over. I may add here that bottles containing medicine fell off the shelf at the house of a town physician, causing so much damage that his patients were deprived of their medicines for two days till he obtained an extra supply from Odawara. On examining my *ando*, a Japanese lamp, the description of which would be familiar to every foreigner who

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has been in Japan,* I found the paper which covered the side facing the sea or E. S. E. was saturated with oil showing that the oil was thrown out on the side toward the sea.

In order to show the effects which the earthquake produced, a brief description of the physical structure of Atami and neighboring coast is necessary.

Atami is built on the slope rising with quite a steep inclination from the sea in a valley formed by the spurs of Hakone ranges, which project out into the sea like arms, enclosing the town of Atami between them. On the south side particularly, the mountain terminates in cliffs of great height and abruptness. The houses are mostly on terraces, built successively from the sea. In fact, the coast of Idzu rises out of the water perpendicularly, thus making the roadway along the coast extremely difficult. The road from Odawara to Atami, a distance of about 16 miles, is cut through mostly along the sides of cliffs, in many places several hundred feet above the sea.

On going out to look for any damage that might have been done, I found that in numerous places, stones were thrown entirely down from their positions in the nearly vertical retaining walls of the terraces. In a similar manner, a solid retaining wall about 5 feet high above which one of the principal hotels, called Suzukiya, is built, was nearly destroyed on the side facing the sea. A little house in front of our hotel was twisted out of shape by the stones giving way beneath. I must not omit to say, however, that the stones are mostly rudely cut and loosely laid in the walls, without mortar, but those forming the walls at the hotel were well shaped and closely fitted, though not cemented.

I noticed that the greatest damage to the terraces, was in the sides facing the sea or E.S.E.; a few cases in those facing

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* *The lamp I had essentially consisted of a shallow box about one foot square with four small posts about three feet high, erected in its corners and braced together at the top by pieces of wood; above the middle, this framework was papered over, having in the inside a narrow piece of board fixed across to hold a copper saucer containing oil with a little wick hanging over the edge.*

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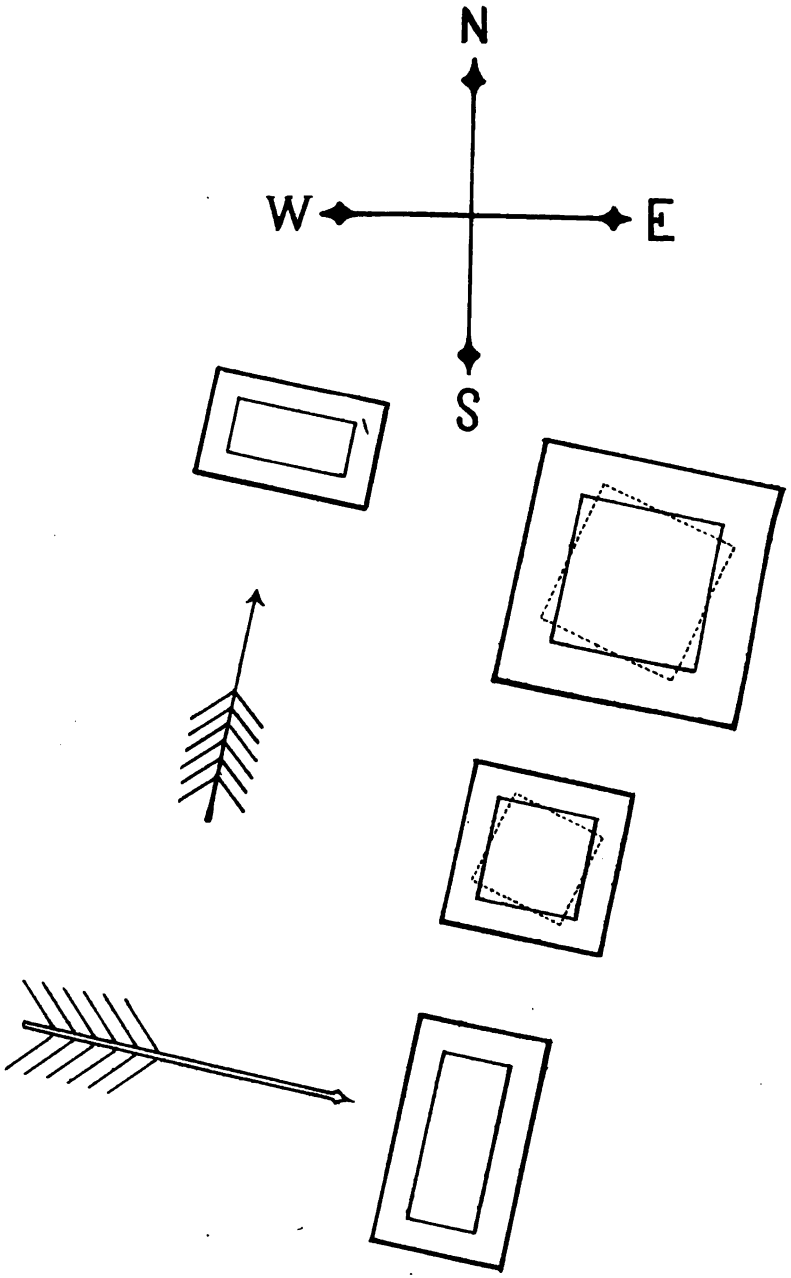

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N.E. & S.E. but scarcely any in those facing S. or S.W. As the land rises towards the W. and N., I found scarcely any walls facing in those directions and no cases of damage in them.

Although most of the walls face E.S.E. and therefore we can hardly tell by the amount of damage, the side which suffered the most, yet it appears most probable that the side facing E. S. E. had to bear the greatest shock.

I have come to the same conclusion as to the direction of the shock by the consideration of the fall and rotation of tombstones in the graveyard of Onsenzi, which I was fortunate enough to observe in their displaced positions, as the workmen were already employed in replacing them properly.

The temple of Onsenzi is located quite a distance up from the sea in an elevated situation with terrace walls on N. N. E. and E.S.E. sides. Just in front of the temple a monument erected in memory of a historical personage Fujiwara Fujifusa, facing N.N.E., fell forwards and was broken. It was a broad irregular flat slab about 6 inches thick, measuring about 5 feet high and 3 feet wide, set into a hole made in the stone base.

Some of the smaller tombstones, which simply rested on flat bases and through bad cutting or disintegration were unstable fell from their pedestals, all toward E.S.E., with the exception of two flat ones facing N.N.E. which fell forwards in the same direction as the monument.

I observed also the interesting case of tombstones rotating on their bases, all in the same direction as that of the hands of a watch. The tombstones all stood in rows parallel to each other and the approximate displacement and the directions of the fall can be seen in the accompanying diagram, the dotted lines indicating the rotated positions; the large arrow shows the direction of the fall of the tombstones and the small arrow that of the monument and the two tombstones mentioned above.

The maximum amount of rotation observed was about 20°, the amount apparently decreasing as the weight of the stones increased.

The simple explanation of rotation of columns given by Prof. Milne in Vol. I of the transactions of this society can be

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applied to this case, regarding the movement as caused by a direct shock, or we can imagine this singular movement as due to the rotary motion of the ground, probably caused by the interference of transverse waves. If we consider the shock as coming from the direction of the sea, the production of the reflected waves could reasonably be accounted for, by the sudden reflection against the dense rocks of which the mountains are composed. The comparative violence of the shock felt here may also be due to the same cause, or to the fact that the origin of the shock was comparatively near.

From what has been recorded we have evidences to infer that the general direction of the shock was either W.N.W. and E.S.E. or W.S.W. and E.N.E. or nearly E. and W. which agrees with the direction indicated by Prof. EWING's astatic lever seismograph in the engineering laboratory of the *Daigaku* on the morning of that day. The seismographic record shows that there was hardly any motion of the lever which traces the N. and S. component, whereas the one indicating the E. and W. component undulated considerably through the comparatively long interval of 69 seconds. On making inquiries about the earthquake at every place where I stopped, I found that the intensity was less and the duration longer than was felt at Atami; at Kanagawa, a man particularly remarked about it, as an unusually long shock. Whether the earthquake recorded in Tokio is the same as that felt at Atami is doubtful, yet it is reasonable to believe that they were the same or at least had originated from the same source as a shock was felt everywhere about the same time, on this side of the Hakone as far as I could ascertain.

We had several smaller shocks after the heavy one I have described; I have recorded one at about 9 and another a little before 12 in the morning of the same day. We were alarmed again about 2 A.M. of Oct 1 by a shock. In the mean time I am certain of feeling slighter ones whose times of occurrence, I have not recorded. About 10 A.M. of Oct 5th I felt a distinct shock.

The frequency of the shocks felt, the comparative violence of the first one with the short duration of apparently rapid

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vibrations, all favor the supposition that the origin of the shocks was near; the waves may have been propagated from a source somewhere in vicinity of Atami, decreasing in amplitude and energy in proportion to the distance traversed. Friends of mine who were in Kiga on the Hakone mountains tell me that they do not remember of feeling any shock that morning, which shows at least that the origin was not in that part of the range.

Being interested in the nature of the mineral springs, I made immediate inquiries as to the action of the big spring or *Oyu*, after the shock. I found that there was no change in the usual periodicity and amount of discharge until two days after, when, on Oct. 1, the discharge continued unceasing for the whole day, which I was informed happens very rarely. This fact may be explained by supposing that the large amount of infiltrated water, derived in great part from the extraordinary heavy rain of Sept. 30th and Oct. 1st, produced an unusual amount of steam and boiling water sufficient to cause this continuous discharge under the influence of unusually great subterranean heat, which might likely prevail at the time of earthquakes, as is evidenced by the sudden increase of temperature in the certain thermal springs; as for instance, at the time of the earthquake of the island of Ischia in the bay of Naples in 1828 the hot springs of Rita which was near the centre of the movement, were ascertained by M. Covelli, to have increased in temperature.(1) After the great New Zealand earthquake in 1855, the natives alleged that the temperature of Taupo hot springs was sensibly raised just before the catastrophe.(2) Concerning the elevation of subterranean temperature, Lyell says "Thermal and mineral springs are abundant in countries of earthquakes and active volcanos. Lastly, springs situated in districts considerably distant from volcanic vents have been observed to have their temperature suddenly raised or lowered, and the volume of their water increased or lessened by subterranean movements. etc. etc."

(1) *Lyell's Principles of Geology vol. II p. 94*
(2) „ „ „ „ „ „ *p. 87*

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On the 3d, however, the spring had resumed its normal condition. Some say that the rainfalls generally increase the amount of discharge, which if true goes to show that the spring is not entirely of marine origin.

It seems quite reasonable to infer that the spring water owes its origin partly to the sea water and partly to the fresh water infiltrations.

Although a digression, let us compare by the use of the following table, the composition of the spring water as analysed by Dr. MARTIN at Shiyakujo and those of the varieties of sea water collected at different localities, to show the analogy existing between them without discussing them in detail.

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(*Contained in 1 litre*)

Localities	Na	Cl	Mg	Ca	K	So_4	Br	Co_3	Fe	Mn	Sio_2	org. mat.	Residue	Authors
Atlantic Ocean 41° 18′ N—36° 28′ W	gr. 11.719	gr. 20.840	gr. 1.1981	gr. 0.5568	gr. 0.6682	gr. 3.029	gr. 0.3878	gr. ,,	gr. ,,	gr. ,,	gr. ,,	gr. ,,	gr. 38.400	BIBRA, *Ann der Chem. u. Pharm.* t. LXXVII
Pacific Ocean 3m, 50 from the surface	10.262	18.950	1.3151	0.4719	0.6038	2.786	0.3102	,,	,,	,,	,,	,,	34.700	BIBRA, *loc. cit.*
Black Sea South side of Crimea	5.512	9.574	0.6622	0.1305	0.0975	1.2505	0.005	0.2475	0.1271	,,	,,	,,	17.605	GÖBEL, *Poggendorff's Ann., suppl.* t. I, P. 187
Sea of Azof between Kertch and Mariopol.	3.997	6.585	0.4010	0.0908	0.0670	0.8045	0.004	0.0695	0.0358	,,	,,	,,	11.900	*Ibid.*
Atami Big Spring (Oyu)	1.491	6.034	0.5894	0.6945	0.9493	0.1362	trace	0.0053	0.0009	trace	0.1100	trace	10.010	MARTIN, *Mittheilungen der Ostasiat. Gesellschaft* July 1876
Caspian Sea South West of Pischnoi	1.144	2.737	0.4098	0.1916	0.1397	1.337	?	0.0773	0.0401	,,	,,	,,	6.296	GÖBEL, *Poggend. Ann., suppl.* t. I

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We find that the total residue of the spring is much less than those of the different samples of the ocean waters generally. Now, we ought rather expect it more on account of concentration by evaporation etc, but the fact that it is less seems to indicate that the sea water is considerably diluted before being discharged.

The comparatively large amount of silica, SiO_2, in the spring is due, no doubt, to the decomposing action of the hot water upon the trachytic rocks underlying Atami through which it has percolated, as is the case in the majority of thermal springs passing through silicious formations.

It seems to be of great value for the proper discussion of the subject to have the analyses of the spring water and those of the sea water near the coast, made from time to time through the varying seasons of the year.

After the shock, however, the little spring called *Kobayashi no yu* which fed the bath of our hotel, was nearly stopped up, discharging but a small amount of muddy water to the general dissatisfaction of the guests and the alarm of the host. On examining the spring, I found that the water did not rise high enough in the basin to be conveyed by the aquaduct. They lowered the aquaduct, which involved considerable trouble, but by doing so the usual supply was obtained. On examining the action of the spring, which is generally intermittent with the interval of 2 minutes or so, I found that it had accelerated its eruptions becoming almost constant but apparently decreased in force.

This fact might be explained by supposing that the tube which conveys the water was distorted and contracted by the recent earthquakes thus hastening the interval of eruptions, just as BUNSEN explained the action of geysers, the truth of which was afterwards experimentally confirmed by Dr. TYNDALL; that is, the tube itself being sufficiently accountable for the production of periodic eruptions, any obstruction of the tube would, by causing the heat to accumulate, tends to hasten the eruptions.

The large amount of boiling water discharged periodically from the *Oyu* accompanied with clouds of steam and growl-

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ing subterranean noise is the object of much wonder and speculation to all who see it during its action. The eruptions take place quite regularly about 5 times in a day lasting for half an hour or more. A few hours before the final eruption clouds of steam begin to issue from the mouth of the tube and the water rises to the rim of the basin, and for a considerable length of time the level of the water in the basin oscillates up and down. The oscillations increase in frequency and force till followed by a number of minor eruptions of shorter duration, the water receding into the tube after each outburst, and commencing again the similar actions with added force and increase in the volume of the discharged water, and so repeating itself again and again tills it ends in the final eruption.

This peculiar oscillating action of the spring does not essentially contradict, even if it does not favor, the theory that the intermittency is due to the formation of steam in the lower part of the tube, as proposed by BUNSEN and others to account for the action of the geysers.

The percolated water coming in contact with heated rocks or superheated steam, would be partly converted into vapour, which in turn will heat up an additional amount of water till the tube full of water will be raised to a high temperature. As the water in the lower part of the tube receives more heat, a sudden rise of temperature, however slight, may cause the water to overcome the pressure and flash into steam which would tend to rush up the tube, carrying the column of water with it; but the enormous pressure of the column would condense part of the steam, which will cause the column to sink down again into the tube. This conflict, so to speak, of steam and the pressure of the water would last for some time and may give rise to the oscillatory movement above described.

At length, however, the tension of the steam becomes so great that the column of water is no longer able to resist it, and it will be pushed out, at first, spasmodically; but as the lower portion becomes relieved of part of its weight and is rapidly converted into vapor, the action will become more violent, till the whole of the column is expelled.

When the expansive power of steam is thus exhausted,

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the sea water may rush into the tube through the underground fissures and may partly full up the tube; at the same time the rain water may be infiltrating into it. The existence of underground fissures from the bottom of the sea near the coast, is evidenced by the fact that the sailors and fishermen often feel the hot water bubbling up from the bottom.

On my way back, I found that the road between Atami and Odawara had suffered some damage, landslips obstructing the passage in many places, which were, no doubt caused by the recent rain aided by the previous earthquake, as in Atami where we found that the rain greatly extended the damage begun by the earthquake.

I must say that as the construction of the houses, terrace walls, &c, is rough and primitive with few exceptions, the amount of damage done here would be far greater than the same intensity would have produced on level ground or in more solid structures or in places where stone constructions are few.

Having no intention of writing this brief note at the time, I must apologize for the inaccuracies both as to time and measurements.

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SEISMOLOGICAL SOCIETY OF JAPAN.

CONSTITUTION.

[CORRECTED TO 1883 JAN. 1.]

1.—This Society shall be called the *Seismological Society of Japan.*

2.—The objects of this Society shall be the furtherance of the study of, and the collection of facts relating to all the phenomena connected with *earthquakes* and *volcanoes.*

3.—At the meetings of the Society papers on general science may be read, subject to the approval of the Society.

4.—This Society shall consist of *Corporation, Honorary* and *Ordinary* members.

5.—*Honorary Members,* who must be non-residents in Japan, shall be admitted on grounds to be determined by the Committee.

6.— }
7.— } Cancelled.

8.—The annual subscription shall be due on January 1st, and shall be, for members who receive the English *Transactions,* 8 *yen,* or £ 1., or $ 5. Japanese members who live in the interior may receive only the Japanese *Transactions,* and in that case the annual subscription shall be 4 *yen.*

9.—The Officers of the Society shall be a *President,* a *Vice-President,* a *Foreign Secretary,* a *Japanese Secretary,* a *Foreign Treasurer,* a *Japanese Treasurer* and five *Ordinary Members,* two of whom shall be residents of Yokohama. These eleven shall form the Committee, of whom four shall form a quorum. The Chairman of the Committee shall have a deciding vote.

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10.—The affairs of this Society shall be managed by the Committee, who shall also decide on the papers to be published in the *Transactions* of the Society.

11.—General Meetings, due notice of which shall be given to the Members by the Secretary, shall be held at convenient dates in Tokio or Yokohama.

12.—The Officers of the Society shall be elected each year by ballot at an Annual Meeting.

13.—The Committee shall hold a Meeting one week before each General Meeting.

14.—At the Annual Meeting the Secretary and the Treasurer shall present their Reports.

15.—Any amendments to this constitution may be proposed at any General Meeting, and shall be considered at the next, when, if two-thirds of the Members are present, it may be passed by a majority vote; if however two-thirds of the Members are *not* present, and the majority of those present are in favor of the amendment, it shall be considered at the succeeding Meeting, when, if a majority of those present are in favor of the amendment, it shall be adopted.

16.—The Secretary shall notify Members of proposed amendments to the constitution.

RULES ADOPTED BY THE COMMITTEE.

[CORRECTED TO 1883 JAN. 1.]

1.—Every paper shall be submitted to the Committee, either in full or abstract, before it is put on the list of the Society for public reading.

2.—Any person presenting a paper to the Society shall be required to state whether he intends to publish it elsewhere.

3.—Each paper shall be submitted to a sub-committee who shall have power to recommend whether it shall be printed in the *Transactions* of the Society *by title, in abstract,* or *in full.*

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4.—The printing, in the Society's *Transactions*, of remarks or criticisms upon papers read at any meeting, shall be limited substantially to what was uttered in public at such meeting; or if any new matter, in the way of further remark or criticism, is offered later, it must first be submitted to the Committee for their decision.

5.—To any new Member of the Society will be given one copy of all the volumes of the *Transactions* published after such Member joins the Society, and to any retiring Member the volumes including the papers read up to the time of such Member's resignation, if all his dues are then paid.

6.—To Members of the Society extra copies of the *Transactions* will be sold at the cost price of publication, which may be learned by application to the Secretary.

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MARCH, 1883.

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* During the temporary absence of the *Foreign Secretary* in Europe.

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SEISMOLOGICAL SOCIETY OF JAPAN.

This Society was organized 1880 March 11, at Tokio, Japan, for the purpose of investigating and studying all the phenomena connected with *earthquakes* and *volcanoes*.

For a copy of its *Constitution*, *Rules*, and *List of Officers and Members*, see page 105 of this volume.

The Society has now published five volumes of *Transactions*, and an abstract of the contents of the first four is given on the preceding page. Below are given the prices for which they can be purchased by the public. *The editions of the first four volumes are nearly exhausted.*

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EARTH PULSATIONS.

BY

JOHN MILNE.

[READ FEB. 15TH, 1883]

For many years philosophers have speculated as to whether the surface of the earth is really so stable as it usually appears. With the sudden and violent motions of our soil which we call Earthquakes man has been familiar since the earliest times, and the origin of these disturbances have always formed a fruitful source of speculation. With the help of properly constructed instruments, our knowledge of the nature of these movements has during the last few years been greatly extended, and we are brought to the conclusion that these natural vibrations are propagated through the surface of our earth in a manner very different to that which we should have anticipated from our knowledge of elastic solids. Another order of earth movements which in the hands of Timoteo Bertelli of Florence, M.S. di Rossi of Rome and other Italian investigators have recently received considerable attention are Earth Tremors. From observations carried on in Italy during the past 10 years it would appear that the soil of that country is practically in a perpetual state of vibration even in districts far removed from volcanic centers. On account of the small amplitude of these motions, they are only to be observed with aid of specially constructed instruments. Messrs. George and Horace Darwin in connection with their experiments on the disturbance of gravity caused by lunar attraction have shown that these movements are common to the soil of Britain. Like observations have been made in Japan and it does not seem improbable that after farther experiments have been carried out we shall be brought to the conclusion that the surface of the whole globe is affected with similar microseismical disturbances.

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In addition to these minute movements which escape the attention of the ordinary observer on account of the smallness of their amplitude, theoretical investigation has also shewn us that there may be existing in the soil on which we live movements which have escaped our attention on account of the slowness of their period. For want of a better term I call these motions Earth Pulsations. Mr. George Darwin in his last report to the British Association has shewn that movements of this nature may be produced by barometrical variation. A rise of the barometer over an area is equivalent to loading that area with a weight, in consequence of which it is depressed. When the barometer falls, the load is removed from the area, which in virtue of its elasticity rises to its original position. This fall and rise of the ground, completes a single pulsation.

On the assumption that the earth is as rigid as steel Mr. Darwin calculates that if the Barometer rises an inch over an area like Australia, the load is sufficient to sink that continent 2 or 3 inches.

The tides which twice a day load our shores cause the land to rise and fall in a similar manner. On the shores of the Atlantic, Mr. Darwin has calculated that this rise and fall of the land may be as much as 5 inches. By these risings and fallings of the land the inclination of the surface is so altered that the stile of a plummet suspended from a rigid support ought not always to hang over the same spot. There would be a deflection of the vertical.

In short, calculation respecting the effects of loads of various descriptions which we know are by natural operations continually being placed upon and removed from, the surface of various areas of the earth's surface, indicate that slow pulsatory movements of the earth's surface must be taking place, causing variations in inclination of one portion of the earth's crust relatively to another. That pulsatory motions of this description have also been observed it may be shewn that there is but little doubt. The magnitude of these disturbances however is so great, that we can hardly attribute their origin solely to the causes which have just been indicated.

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Rather than seek an explanation from agencies exogenous to our earth we might perhaps with advantage appeal to the endogenous phenomena of our planet. When the barometer falls which we have shewn corresponds to an upward motion of the earths crust, we know from the results of experiment that microseismic motions are particularly noticeable.

As a pictorial illustration of what this really means, we may imagine ourselves residing on the loosely fitting lid of a large cauldron, the relief of the external pressure over which, increases the activity of its internal ebullition—the jars attendent on which are gradually propagated from their endogenous source to the exterior of our planet. This traveling outwards would take place much in the same way that the vibrations consequent to the rattle and jar of a large factory slowly spread themselves farther and farther from the point where they were produced.

Admitting an action of this description to take place, it would then follow that this extra liberation of gaseous material beneath the earth's crust would result in an increased upward pressure from within, and a tendency on the part of the earth's crust to elevation. If we accept this as an explanation of the increased activity of a tremor indicator, then such an instrument may be regarded as a barometer, measuring by its motions the variations in the internal pressure of our planet.

The relief of external pressure and the increace of the internal pressure it will be observed both tend in the same direction, namely to an elevation of the earth's crust.

This explanation of the increased activity of earth tremors which I believe is one suggested by M. S. di Rossi, is only advanced as a speculation—more probable perhaps than many others. We know how a mass of sulphur which has been fused in the presence of water, in a closed boiler, gives up in the form of steam the occluded moisture upon the relief of pressure. In a similar manner we see steam escaping from volcanic vents and cooling streams of lava. We also know how gas escapes from the pores and cavities in a seam of coal on the fall of the barometrical column. We also know

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that certain wells increase the height of their column under like conditions. The increase in the quantity of water flowing from an area consequent on diminution of atmospheric pressure, may, by rendering an area of less weight, facilitate its rise.

The next question is as to whether we have direct evidence of such heavings and sinkings in our earth's crust; the possibility of which has here been indicated.

Although some of the proofs which are brought forward to show that slow pulsations like these have been repeatedly observed, are unsatisfactory, taking them one with another they indicate that these pulsatory phenomena have a real existence.

Pendulums for instance which have been suspended for the purposes of seismometrical observations, have both by observers in Italy and Japan been seen to have moved a short distance out from, and then back to, their normal position.

This motion has simply taken place on one side of their central position and is not due to a swing. The character of these records is such, that we might imagine the soil on which the support of the pendulum rested, to have been slowly tilted and slowly lowered. They are the most marked on those pendulums provided with an index writing a record of its motions on a smoked glass plate,—the index being so arranged that it gives a multiplied representation of the relative motion between it and the earth. As motions of this sort might be possibly due to the action of moisture in the soil tilting the support of the pendulum and to a variety of other accidental causes, we can not insist on them as being certain indications that there are slow tips in the soil, but for the present allow them to remain as possible proofs of such phenomena.

Evidence of displacement of the vertical which are more definite than the above are those made by Bertelli, Rossi, Count Malvasi and other Italian observers, who whilst recording earth tremors have spent so much time in watching the vibrations of stiles of delicate pendulums by means of microscopes. As a result of these observations we are told that the point about which the stile of a pendulum oscillates, is variable.

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These displacements take place in various azimuths, and they appear to be connected with changes of the barometer.

From this and from the fact that it is found that a number of different pendulums differently situated on the same area give similar evidence of these movements, it would hardly seem that this phenomena could be attributed to changes in temperature, moisture and the like. M. S. di Rossi lays stress on this point especially in connection with his microseismograph, where there are a number of pendulums of unequal length which give indications of a like character. The direction in which these tips of the soil take place, which phenomena are noticeable in seismic as well as microseismic motions, Rossi states are related to the direction of certain lines of faulting.

Bubbles of delicate levels when examined by a microscope change their position with meteorological variations, but Rossi also tells us that they change their position, sometimes not to return for a long time during a microseismic storm. Here again we have another phenomena pointing to the fact that microseismic disturbances are the companions of slow alterations in level. The more definite kind of information which we have to bring forward, tending to prove the existence of earth pulsations too slow in period, to be experienced by ordinary observers, are those which appear to be resultant phenomena of great earthquakes.

The phenomena that we are certain of, in connection with earth vibrations, whether these vibrations are produced artificially by explosions of dynamite in bore holes, or whether they are produced naturally by earthquakes, are, firstly that a disturbance as it dies out at a given point often shows in the diagrams obtained by seismographs a decrease in period, and secondly, a similar decrease in the period of the disturbance takes place as the disturbance spreads.

As examples of these actions I will refer to the diagrams which I have given in a paper on the Systematic Observation of Earthquakes in Vol. IV of the Transactions of the Seismological Society of Japan.

In a diagram of the disturbance of March 1st 1882 it

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seems that the vibrations at the commencement of the disturbance had a period of about 3 per second, near the middle of the disturbance the period is about 1.1 whilst near the end the period has decreased to .46. That is to say the back and forth motion of the ground at the commencement of the earthquake was 6 times as great as it was near the end, when to make one complete oscillation it took between 2 and 3 seconds. Probably the period became still less, but was not recorded owing to the insensibility of the instruments to such slow motions.

We have not yet the means of comparing together continuous diagrams of two or more earthquakes, one having been taken near to the origin and the other at a distance. The only comparisons which I have been enabled to make have been those of diagrams taken of the same earthquake,—one in Tokio and the other in Yokohama. As this base is only 16 miles and the earthquake may have originated at a distance of several hundreds of miles, comparisons like these can be of but little value.

The best diagrams to illustrate the point I wish to bring forward, are those at the end of the above mentioned paper. These are the results obtained at three stations in a straight line, but at different distances from the origin of a disturbance produced by exploding a change of dynamite in a bore hole. A simple inspection of the diagrams here referred to, shows that at the near station the disturbance consisted of back and forth motions which as compared with the same disturbance as recorded at a more distant station were very rapid. Farther by examining the diagram of the motions say at the near station, it is clearly evident that the period of the back and forth motion rapidly decreased as the motion died out.

These diagrams are referred to, as examples out of a large series of other records, all showing like results.

Although we must draw a distinction between earth waves and water waves, we yet see that in these points they present a striking likeness. Let us take for example any of the large earthquake waves which have originated off the coast of South America and then radiated outwards, until they

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spread across the Pacific to be recorded in Japan and other countries perhaps 25 hours afterwards, at a distance of nearly 9000 miles from that origin. Near the origin they appeared as walls of water which were seen rapidly advancing towards the coast. These have been from 20 to 200 feet in height and they succeeded each other at rapid intervals, until finally they died out as gentle waves. By the time these walls of water traversed the Pacific, let us say, to Japan, they broadened out to a swell so flat that it could not be detected on the smoothest water, excepting along shore lines where the water rose and fell like the tide. Instead of a wall of water 60 ft. in height we had long flat undulations perhaps 8 ft. in height, but with a distance from crest to crest of more than 120 miles.

If we turn to the effects of large earthquakes as exhibited on the land, I think that we shall find records of phenomena which are only to be explained on the assumption of an action having taken place analogous to that which takes place so often in the ocean, or an action similar to that exhibited by small earthquakes and artificially produced disturbances greatly exagerated.

As a remarkable instance of such phenomena we may take the great earthquake of Lisbon (Nov. 1st 1755). In Spain, Northern Italy, the South of France and Germany, Northern Africa, Madiera and other Atlantic islands, the effects of the disturbance which created so much devastation in Portugal, were also more or less severely felt as violent movements of the soil.

In other countries further distant as for instance, Great Britain, Holland, Norway and Sweeden, and North America, although the records are numerous, the only phenomena which were particularly observed were the slow oscillations of the waters in lakes, ponds, canals &c. In some instances the observers especially remark that there was no motion in the soil.

Pebley Dam in Derbyshire which is a large body of water covering some 30 acres, commenced to oscillate from the South.

A canal near Godalmin flowed 8 ft. over the walk on the north side.

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Coniston water in Cumberland which is about 5 miles long, oscillated for about 5 minutes, rising a yard up its shores. Near Durham a pond 40 yds. long and 10 broad rose and fell about 1 ft. for 6 or 7 minutes. There were 4 or 5 ebbs and flows per minute.

Loch Lomond rose and fell though about 2½ ft. every 5 minutes; and all other Lochs in Scotland seem to have been similarly agitated.

At Shirburn Castle in Oxfordshire where the water in some moats and ponds was very carefully observed, it was noticed that the floods began gently—the velocity then increased, till at last with great impetuosity they reached their full height. Here the water remained for a little while, until the ebb commenced at first gently but finally with great rapidity. At two extremities of a moat about 100 yds. long it was found that the sinkings and risings were almost simultaneous. The motions in a pond a short distance from the moat were also observed, and it was found that the risings and sinkings of the two did not agree. During these motions there were several maxima.

These few examples of the motions of waters without any record of the motions of the ground, at the time of the Lisbon earthquake, must be taken as examples of a very large number of similar observations of which we have detailed accounts.

Like agitations it must also be remembered were perceived in North America and in Scandinavia, and if the lakes of other distant countries had been provided with sufficiently delicate apparatus, it is not unlikely that like disturbances would have been recorded.

The only explanation for these phenomena appears to be that the short quick vibrations which had ruined so many cities in Portugal, had by the time they had radiated to distant countries gradually become changed into long flat waves having a period of perhaps several minutes, and in countries like England these pulse like movements were too gentle to be perceived excepting in the effects produced by tipping up the beds of lakes and ponds.

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The phenomenon was not unlike that of a swell produced by a distant storm.

At Amsterdam and other towns, chandeliers in churches were observed to swing. At Harlem floods rose over the sides of tubs and it is expressly mentioned that no motion was perceived in the ground.

At the Hague a tallow chandler was surprised at the clashing noise made by his candles and this the more so because no motion was felt under foot.

At Toplitz the pulsations of the ground appear to have manifested themselves in effects upon the springs. The flow of the principal spring was greatly increased. Before this increase it became turbid and at one time stopped. Subsequently it became clear and flowed as usual, but the water was hotter and more strongly mineralized.

At one or two places as for instance in Britain slight earthquakes were experienced. These however were local and in every probability were secondary disturbances produced by the pulsations causing ground in a critical state to give way.

In this earthquake I think then, that we have a clear case of the production of pulsations in the soil too slow to be felt by ordinary observers.

Motions like these might be called slow earthquakes, and it is not unlikely that they are the resultants of all large disturbances. When they accompany a large earthquake like that of Lisbon, their cause is evident. But when we see the waters of lakes and ponds oscillating, the bulbs of levels disturbed, and the plumment line of pendulums displaced the reason of these phenomena is not so apparent. It would seem possible that in some cases pulsations producing these phenomena might have their origin beneath the oceans or deep down beneath the earth's crust. Perhaps instead of commencing with the snap and jar of an earthquake, they may commence as a heaving or sinking of a considerable area which may be regarded as an uncompleted effort in the establishment of an earthquake or a volcano. The very fact that volcanoes rising from deep oceans have in the first instance forced their way against a pressure of at least 3 or 4

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tons to the square inch, indicates to us the existence of internal pressures tending to raise the crust of the earth which pressures are infinitely greater than any of the pressures which we have upon the surface of our earth produced by tides and variations in the barometrical column. If we follow the views of Mallet in considering that the pressures exerted on the crust of our earth may in volcanic regions be roughly estimated by the height of a column of lava in the volcanoes of such districts, we see that in the neighbourhood of a volcano like Cotopaxi the upward pressures must have been many times greater than the pressures already mentioned,—sea level being taken as the line of hydrostatic equilibrium. The chief point however, is that beneath the crust of our earth enormous pressures exist tending to cause eruption—and farther, that these are variable. Before a volcano bursts forth we would expect that there should be in its vicinity an upward bulging of the crust and after its formation, a fall. Farther it is not difficult to conjecture other possible means by which such pressures may obtain relief.

Should these pressures then find relief without rupturing the surface, it is not difficult to imagine them as the originators of vast pulsations which may be recorded on the surface of the earth as wave like motions of slow period, similar to the motions in the outer area of a tract disturbed by a destructive earthquake.

If slow undulatory motions or changes in the vertical do occur in the crust of the earth, whatever may be their origin, we have numerous phenomena which certainly admit of explanation on such an assumption.

In Switzerland from time to time we hear of oscillations in the waters of lakes known under the name of Rhussen and Seiches. These it may be remarked are common to the lakes and inland seas of many countries.

Other examples of what may have been a slow oscillating motion of the earths crust are referred to by Mr. George Darwin in his Report to the British Association in 1882.

One of them was made, by M. Magnus Nyrén at Pulkova who when engaged in levelling the axis of a telescope observed

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spontaneous oscillations in the bulb of the level.

This was on May 10 (April 28) 1877. The complete period was about 20 seconds, the amplitude being 1".5 and 2". One hour and 14 minutes before this he observes that there had been a severe earthquake at Iquique, the distance to which in a straight line was 10,600 kilometers and on an arc of a great circle 12,500 kilometers. On Sept. 20 (8) in 1867 Mr. Wagner had observed at Pulkova oscillations of 3", seven minutes before there had been an earthquake at Malta.

On April 4 (March 23) 1868 an agitation of the level had been observed by M. Gromadzki, five minutes before there had been an earthquake in Turkestan. Similar observations had been made twice before. These however had not been connected with any earthquakes—at least, Mr. Darwin remarks, with certainty. Like phenomena are mentioned by M. S. di Rossi in his Meteorologia Endogena.

Thus on March 20th 1881 at 9 P.M. a watchmaker in Buneos Ayres observed that all his clocks oscillating North and South suddenly began to increase their amplitude, until some of them became twice as great as before. Similar observations were made in all the other shops. No motion of the earth was detected. Subsequently it was learnt that this corresponded with an earthquake in Santiago and Mendoza.

Another remarkable example illustrating the like phenomena is the observation which was made on Dec. 21 1860, by means of a barometer in San Francisco, which oscillated with periods of rest for ½ an hour. No shock was felt, nor is it likely that it was a local accident as it could not be produced artificially. On the following day however a violent earthquake was experienced at Santiago.

This brings me to the end of the few important illustrations of the phenomena of Earth Pulsations which I have at my disposal. With a little trouble I have no doubt that these might be greatly multiplied. As they stand however I think that they are quite sufficient to convince us of the existence of phenomena which hitherto have been almost entirely overlooked. That disturbances of the vertical are from time to

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time produced by long pulse like waves can hardly be doubted. These however are phenomena of a different order to those which were so carefully sought for by the Darwins at Cambridge.

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NOTE ON THE DEVELOPEMENT AND INTERPRETATION OF THE RECORD WHICH A BRACKET MACHINE GIVES OF AN EARTHQUAKE.

BY

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[READ FEB. 15TH 1883]

Figures 1 and 2 are for the purpose of reference in the geometrical demonstration for an out and in stroke respectively, and are not to scale, nor in any way intended to represent either a record of any one earthquake or that of the typical earthquake.

Our data are the path of the pointer traced upon the plate by the unknown motion of the pointer relative to the earth, the known constant angular velocity of the mutual rotation of the plate and the earth, the length of the pointer, and the distance from the centre of plate to the hinge of pointer.

Which data are sufficient to determine the direction and velocity of the draw point relative to the earth while it was at any given point of the path traced on the plate as will be shewn. The other end of pointer being hinged to the earth it is evident that the path of the draw point is a circular arc (very small in the typical record). The data also give us the length of the arc, and point for point on it, corresponding to any out or in stroke of the traced path. Hence the motion of the draw point in its circular path relative to the earth is determinate at each point. Hence the character of the motion of the draw point relative to the earth, in the small circular arc is an oscillating motion in a sensibly straight line, whose velocity at each point is determinate. To assume that this motion is S. H. is to beg the question. And the object of this

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paper is to point out that for the first two or three large strokes (which after all are the record of the earthquake shock) it is *impossible* to assume the motion S. H. For the remainder or tail of record it is always *possible* to assume the motion S. H., and it is just to do so, as it is in all probablity the record of the oscillation of the stand in its own natural period. It may be interesting to measure this, but the thing of greatest interest to this Society is to be sure of the *nature* of the actual shock, and then to measure it. I do not say that the actual shock does not produce a comp. S. H. motion or that it is unreasonable to assume it does. On the other hand I think it is probably S. H. and so conclude, that since the Bracket Machine's record indicates that it is not S. H. as just stated, that therefore the machine is imperfect in practice and worse than useless as it gives misleading results.

Construction figs. 1 or 2. From 0 the centre of plate draw the circle *abc* with radius equal to the distance to hinge of pointer. From B, one end of a wave, with B*b* equal to length of pointer make an arc cutting *abc* in *b* and join B*b*, similarly lay down C*c* equal to the length of pointer. Then it is evident, that the inclination of B*b* and C*c** is the angle of the semi-oscillation made by the pointer relative to the earth, while the tracing point travelled over the portion BAC of its path. Shift *c*C parallel to itself, till *c* coincides with *b*,* then the distance between the extremities C and B is the double amplitude of that semi-oscillation. Choose A any point on

* After the paper was read it was pointed out separately by Professors West and Paul that from the inclination of the dotted pointers in fig. 1 the angle *boa* must be subtracted and to that inclination in fig. 2 the angle *b′o a′* must be added to give the angle of the semi oscillation made by the pointer relative to the earth. Since however this additional angle is discribed at constant rate, it in no way invalidates the fact that A is the point on path corresponding to the middle point of circular arc if A*a* in direction is midway between the directions of the dotted pointers. Of course this correction must be made on the angle to get the double amplitude of the oscillation. Mr. West demonstrated to me by the machine itself that the double amplitude is correctly and quickly got by taking the distance between the concentric circles from O through B and C.

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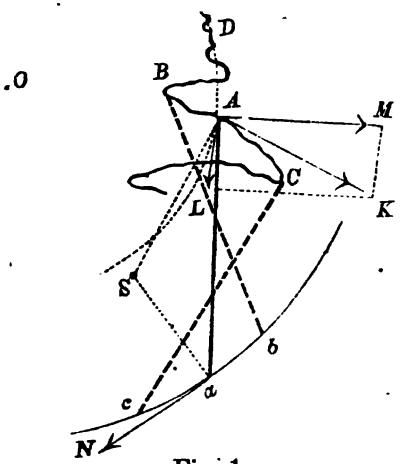

Fig. 1.

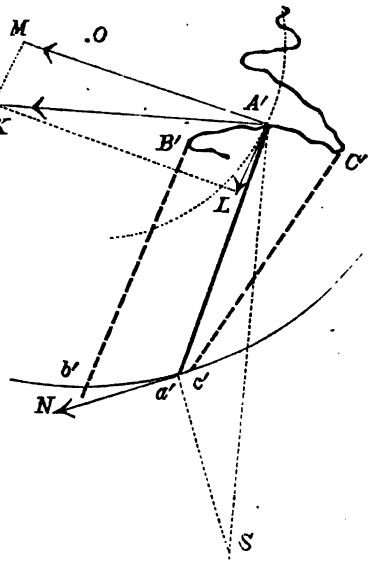

Fig. 2.

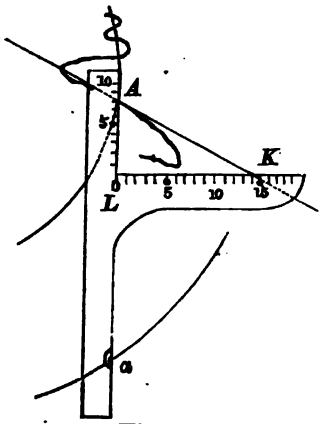

Fig. 3.

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the path near the middle of BC and lay down A*a* equal to length of pointer as above.

If A*a* bisect the angle between B*b* and C*c*, then, while the tracing point was at A, the pointer A*a* was at the middle of the semi-oscillation, and consequently the point A was at the max. velocity for the semi-oscillation. After a trial or two A may be found to satisfy this condition.

While the pointer is in the position A*a*, by considering the plate to be at rest, we see that *a*N, the tangent at *a*, is the direction of the motion of *a* relative to the plate and that AK the tangent to the path at A is the direction of the motion of A relative to the plate. Hence S, where AS the normal to path of A meets the radius *a*S, is the instantaneous axis for the relative rotation of the pointer and plate. If *a*N be laid off to scale equal to the product of the known angular velocity of plate relative to earth into radius O*a*, it will represent the velocity of *a* relative to the plate and AK laid off, bearing the same ratio to *a*N as SA bears to S*a*, will represent the velocity of A relative to the plate.

Let E be the point on the earth below A, then AL laid off along the tangent to the circle through A and equal to the product of the known angular velocity into OA, will represent the velocity of E relative to plate.

On AK as a diagonal construct the parallelogram ALKM then will AM represent the velocity of A to E, that is, it will be the max. velocity of the tracing point during the semi-oscillation of the pointer relative to the earth, while the tracing point travelled over BAC. We have therefore the amplitude and the velocity of the point in the relative circle for the semi-oscillation of the tracing point relative to the earth, sensibly simple hamonic, from which we can calculate the max. acceleration at B or C the extremities of the amplitude by dividing the square of AM by the amplitude.

It follows of necessity that AM is at right angles to *a*A which is a check upon the construction, rendered essential, by the fact that this graphical solution depends upon the accuracy with which AK, the tangent to the path at A, is drawn.

By comparing figs. 1 and 2 it will be seen that the dotted

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pointers cross in the one and do not cross in the other. This will geometrically account for the fact that the successive out and in strokes of path are of markedly different lengths, observed alike on the actual record of an earthquake, and upon the path traced by the pointer when constrained to oscillate by a pendulum. What I mean is, that the fact of the difference of the lengths of the out and in stokes does not necessarily point to the out and in reciprocating motion of the point relative to earth as differing either in magnitude or velocity.

In the bracket machine the pointer A*a* is set sensibly along the tangent at the point of contact while the machine is at rest. If DA be the circle which it traces out when the plate revolves while the pointer remains at rest and if we find or assume that A, the intersection of the path with this circle, is the middle of the semi-oscillation, it follows that AL will lie along A*a* and AM or LK the velocity of tracing point relative to earth is readily found as shewn on fig. 3, thus.—On the template lay off LA to scale to represent the lineal velocity in the circle DA corresponding to the rotation of plate and lay off A*a* equal to length of pointer.—Place the template with A at the junction of path and circle and *a* on outer circle then read of LK intercepted by AK the tangent to path at A.

At the point A fig. 3 which is the junction of path and neutral circle, LK = LA cot AKL is the velocity of tracing point into cotangent of the slope of path to radius at A; so that if path cross neutral circle at right angles LK the vel. of oscillation is infinite, if path lie along neutral circle LK the vel. of oscillation is zero.

From figs. 1 and 2 it is evident, that the instantaneous axis for the rotation of the pointer relative to the plate will fall alternately inside and outside of the circle *cab*.

I examined the path traced by a pointer constrained to oscillate by means of a pendulum. First the pointer was placed as nearly as possible, by inspection, at right angles to the radius and the plate allowed to rotate slowly. The tangent to inward stroke appeared to be along the radius which we

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know is impossible. That is to make the construction with the data, the length of pointer and its angle to radius assumed to be set at a right angle, gave an impossible result. When the construction was made with the strictly measured data the instantaneous axis fell as in figs. 1 and 2 alternately for out and in stroke. Again when the pointer was placed obliquely, so as to make the angle LA*a* about 70°, and the radius of the circle *bac* was found by laying off the length of pointer normal to the arc of circle traced while the plate had been at rest, the construction for in stroke fig. 2 threw S inside *b'a'c'*; but decreasing the radius of *bac* by only 2 p.c. caused both constructions fig. 1 and 2 to be real and gave a gradually decreasing vel. for each semi-oscillation. This shews the necessity of having an actual measurement of the distance between centres of plate and of pointer. When the plate ran quickly it was clearly seen that the zigzags ran alternately on different sides of the centre.

I examined also the path traced by an elastic pointer placed sensibly at right angles to a radius, and made to vibrate upon the plate. I found it impossible to find one circle *cab* such, that S would fall upon different sides of it for alternate strokes, shewing that the elastic arc traced by the pointer cannot be assumed to be circular.

And lastly I examined the registers of different large earthquakes, made by the bracket machine with its pointer sensibly at right angles to the radius point of contact when at rest. The construction for the first few in strokes either by fig. 3 on the assumption of the right angle or by fig. 2 gave an impossible result, as S always fell inside *b'a'c'*.—Impossible, I mean, upon the hypothesis that the plate was rotating constantly and the pointer oscillating with a S.H. motion. That the plate was rotating constantly in one direction, and with an almost constant rate, was shewn beyond all doubt on the margin by hatches made with a pendulum. Hence the inference pointed at is, that the tracing point was not simply oscillating in an arc of a circle with respect to the earth or that the distance between centre of plate and hinge of pointer was varying periodically. I consider, that the earthquake

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record resembles more closely the path traced by the vibrating elastic pointer than that traced by an oscillating pointer and infer, that the pointer of the bracket instrument traces, relative to the earth, some elastic curve during an earthquake rather than a circular arc.

I submit—That time records taken by inspection from the path traced upon a circular plate by the bracket machine, after the fashion of a clock face, whether by drawing radii or arcs with a constant circular template, are deceptive as they may involve the fallacy that a point can move in two circles at a time—That results accurately developed upon the cinematical principles of figs. 1, and 2, but upon the assumption that the pointer was set at right angles to a radius in this instrument, which has no fine adjustments, and could not be expected to remain in adjustment, are worthless for the in stroke, even when we know that the pointer was constrained to oscillate in an arc of a circle—That the development by figs. 1 and 2 for the path traced by a point constrained to oscillate in an arc of circle, even when the measured lengths are given, is a very delicate exercise in draughting—And that the large in strokes on the earthquake records, which were given to me by Mr. Milne, lead to an impossible result on the assumption that the tracing point was oscillating in a circular arc about the hinge of pointer while the distance between centre of plate and hinge remained constant.

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ON A DUPLEX PENDULUM WITH A SINGLE BOB.

BY

PROF. J. A. EWING.

[READ FEB. 15. 1883.]

This instrument is a modification of the Duplex Pendulum exhibited and described to the Society at its last meeting. It is a seismometer capable of recording motion in any azimuth; and its novel feature lies in the method by which a state of neutral equilibrium is produced in a heavy mass free to move in a horizontal plane.

The heavy mass or bob is supported partly by a vertical strut pivotted in a socket which is fixed to the earth, and partly by a stretched tie attached to another fixed point vertically above the first, and above the bob. The tie, which may conveniently be a spiral spring, is stretched to a considerable extent when the bob is undisturbed, and hence any small horizontal displacement does not sensibly increase the tension of the tie. To secure neutral equilibrium the three forces acting on the bob, namely (1) its own weight, (2) the pull of the tie, (3) the thrust of the strut, must balance each other when the bob is slightly displaced out of the vertical line joining the supports. This condition is fulfilled by making the pull of the tie bear to the thrust of the strut the same ratio as the length of the tie bears to the length of the strut. In other words, the weight of the bob must be shared between the tie and the strut in proportion to their respective lengths.

The instrument is, in fact, a vertical pendulum, single with respect to its bob, but duplex with respect to its suspension. Its relation to the duplex pendulum referred to above is made obvious by conceiving the bob to consist of two parts, of which one has its weight borne by the strut and the other

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by the tie. This separation into two parts was actual in the instrument formerly described; here it is imaginary, and in this respect the new instrument has the advantage of greater simplicity in construction and a more complete absence of friction.

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NOTE ON A CASTING SUPPOSED TO HAVE BEEN DISTURBED BY AN EARTHQUAKE

BY

F. GERGENS. C.E.

[MAY 3RD 1883]

Mr. F Gergens exhibited a casting in iron, the surface of which was covered with a series of interlacing irregular ridges. As this casting had been made on the night of an earthquake it was thought probable that the shaking had acted on the molten iron before cooling.

This casting with others was poured about 10.45 P.M. on Jan. 17th. All the castings poured at this time had similar rough ridges on their surface. The moulds were made by different men, but from the same sand. Those which were poured subsequently turned out all right.

It is not known whether an earthquake occurred just after the pouring, but there were several earthquakes about this time. One shock was recorded at 4.45 A.M. on the 18th Jan.

A long discussion followed Mr. Gergens' remarks, and it was suggested that the experiment be made of shaking the mold of a similar casting while the metal was cooling, to see if similar results could be obtained.

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SUGGESTIONS FOR A NEW TYPE OF SEISMOGRAPH.

BY

CHAS. D. WEST. M.A. C.E. M.I.M.E.

[READ MAY 3RD 1873.]

The great problem in the construction of all seismographic machines is to obtain a perfectly steady point from which the vibrations of the earth's surface can be measured. This problem has never been completely solved, but a great number of machines have been made which give an approximate solution of it. The principle of all these machines is the same; a heavy mass is suspended astatically, that is to say, it is suspended in such a manner, that, if it receives a small displacement no force is developed tending to restore it to its original position; and therefore conversly, if the point of suspension of the mass receives a small displacement there is no force developed tending to move the mass.

The motion of the point of suspension or of the framing of the machine, which is assumed to be the same as the vibratory motion of the earth's surface, is what has to be observed, and in general this is automatically recorded by the machine itself.

So far as regards this problem, it is impossible to suspend a heavy mass so as to be astatic in every direction, the nearest approximation to this being a weight suspended by a very long spiral spring or india rubber cord. In most of the machines that have been made it has been found advisable to so suspend the weight as to indicate motion in one direction only, and to use two separate machines to obtain the two horizontal components of the earthquake motion. To obtain either of these components accurately, the suspended mass should be capable of motion in a given horizontal line, and be incapable of motion in any other direction.

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Now for the various modes of suspension which have as yet been adopted, the range of motion is extremely small within which the suspended mass may be considered to be astatic and to move in a straight horizontal line.

There is on the table a model of an arrangement of astatic suspension which as far as I know has not been yet applied to a seismograph; but it may be readily recognized as the form of parallel motion that is used in Richard's Indicator. In this mode of suspension the range of motion within which the heavy mass may be considered to move in a straight line and to be astatic is greater, I believe, than that which has been obtained in any other way; omitting the consideration of methods in which the frictional resistances are obviously excessive.

The first idea of this machine was a single spherical or cheese-shaped weight pivoted on an axis passing through its centre to a set of links and radius rods on each side of it, as shown in elevation in Fig. I.

In the model as made, however, it was decided to try it with two sets of links and radius rods, and the weight then takes the form of a heavy bar; Figures II & III are a side elevation and section; an addition was afterwards made of a guide rod, fastened along the top of the bar and passing through the frame, so as to completely stop any horizontal motion other than the required one, the end of this guide rod also forms a convenient place for attaching a rod leading to any recording apparatus that may be adopted.

In the model on the table, being but roughly made, the friction is much greater than it need be with good workmanship; the pivots might be made a great deal smaller than they are in the model, or knife edges might be adopted instead of axles. The radius rods might also be made longer and the upper ones might be made of cord. In this way the friction might be reduced sufficiently to make the machine more effective.

Another point that is worth consideration in this machine (and also in all the others) is the size of the weight. Since the power required to move a given recording apparatus, or

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arm carrying a pencil, is a constant, and is derived from the inertia of the weight, therefore the larger the weight is, the less it is affected by the friction of the recording gear. On this account the weight which in the model is only about 2 lbs might be made, I think, with advantage as heavy as 50 lbs.

In conclusion I may state that it was Mr. Milne who took all the trouble of having the model made.

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ON CERTAIN METHODS OF ASTATIC SUSPENSION

BY

PROFESSOR J. A. EWING.

[READ JUNE 1ST 1883.]

The mass whose inertia is to give steadiness in a seismometer may be hung in neutral or nearly neutral equilibrium by any system of links which produces an exactly or approximately straight-line motion, provided the links are placed so as to make its line of motion horizontal. An example of this was furnished by the model exhibited by Professor West at the last meeting of the Society, in which a heavy bar was hung by a system of links forming part of the so-called parallel motion of Watt. Or to take another example, we might suspend a mass by a pair of Peaucellier linkages, with freedom to move horizontally, and thereby obtain absolute astaticism throughout the whole range of its motion; or, by reducing the distance between the two pivot points in each linkage, we might compel the mass to move in an arc of very large radius, and thereby give it the slight stability needful in a seismometer. But this plan would be open to the same objection as the suspension by Watt's linkage proposed by Mr. West,—the multiplicity of joints would give rise to an intolerable amount of friction.

To avoid friction we should select a form of linkage with as few links as possible, and these all ties, in order that we may easily substitute flexible cords for rigid pieces with joints. No linkage satisfies these conditions better than the approximate straight-line motion of Tchebicheff, illustrated in the sketch. *A A* are fixed supports *B B* are two equal links, which, when the apparatus takes this form, may be flexible cords. They cross each other and are connected to the end of a hanging bar *C*. The vertical distance of the middle of *C*

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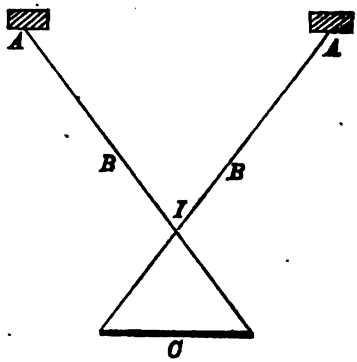

from the line AA is equal to the distance AA, while the length of the hanging bar is $\frac{1}{4}AA$. Then the middle point of the bar moves in a line which is very approximately straight and parallel to AA, provided its excursions lie within a range not greater than the distance between the fixed supports. These proportions will give sensible astaticism when AA is horizontal; but by making the depth of the hanging bar somewhat greater, or by placing the centre of gravity of the hanging bar below the line of its attachment to the links BB, we may give it any desired amount of stability.

When BB are single cords the system is azimuthally unstable, but it is easily prevented from rotating about a vertical axis by making each of the suspending links B double, in two parts which form a V whose vertex is at the end of C, and whose base is a line through A perpendicular to the plane of the paper. Further, this prevents oscillation perpendicular to the plane of the paper, and so leaves none but the desired freedom. To increase the steadiness we may add a mass which should be as much as possible concentrated at the centre of C. This may be pivotted about a horizontal axis perpendicular to C, through its centre, and in that case the mass is equivalent to a particle concentrated there. Figs. 1 and 2 show this arrangement in elevation and plan. There the hanging bar is a light platform on which a heavy lead weight is pivotted about the axis ii on the points of two steel screws, which press up into a conical hole and V-slot in a bar j to which the weight is rigidly attached.

Another plan is to use a pair of light suspended platforms, in line with each other, and use them to carry a mas-

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sive block by three sharp feet which press into a hole and V-slot on one platform, and a V-slot parallel to these on the other. This arrangement is shown in figs. 3 and 4.

But in both of these arrangements the friction at the pivots by which the weight rests on the hanging platform is a disadvantage, which is all the more felt because the platform tilts up through a considerable angle when displaced from its mean position. For this reason the writer prefers the very simple form shown in figs. 5 and 6. There the bob or heavy mass is a piece of lead rigidly fixed to the hanging bar. The effect of this is that when a horizontal displacement of the ground occurs, in the line of the bar, the centre of the bar does not remain at rest, but moves through a small determinate distance in the same direction as the ground.

Let M be the mass of the hanging piece (including the rigidly attached bob), and let Mk^2 be its moment of inertia about its central transverse axis. When the hanging piece is displaced, its motion is one of rotation about its instantaneous axis, which is always situated at the intersection of the suspending cords (the point I in the woodcut). It is easy to show that, for any moderate displacement, this axis moves in a sensibly horizontal direction, and through the same distance as the centre of the bar. Hence the angular displacement of the bar is, very nearly, proportional to its linear displacement, and is equal to the latter divided by h, where h is the height of the instantaneous axis I above the bar. As regards its resistance to rotation, the hanging piece is therefore equivalent to a particle of mass M whose velocity-ratio relative to the centre of the bar is sensibly constant, and equal to $\frac{k}{h}$. Hence the extra inertia due to rotation is $\frac{Mk^2}{h^2}$, referred to the centre of the bar.

When a horizontal displacement of the supports occurs, we may consequently consider the whole system as consisting of a particle M together with a connected particle $\frac{Mk^2}{h^2}$, of which only the first is effective in producing steadiness,

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although both are constrained to share the same motion. The piece will therefore suffer an acceleration in the same direction as the acceleration of the supports, and bearing to it the ratio $k^2 : h^2 + k^2$. The centre of the bar will be displaced in the direction of the displacement of the supports, and in the same proportion; and any measurements of earthquake motion which are taken with reference to the centre of the bar as a datum-point must be multiplied by $1 + \frac{k^2}{h^2 + k^2}$ to find the true displacement of the ground. When the bob is a lump of lead whose dimensions are small compared with the length of the hanging bar, this factor differs very little from unity.

Two light bars with dense rigidly attached bobs, and suspended by silk threads so as to swing at right angles to each other, form an excellent two-component seismograph, especially suitable for the measurement of large earthquakes. The complete absence of joints makes the frictional resistance exceedingly small: in this respect the method of suspension now under examination constrasts very favourably with most other methods. Moreover the construction, and also the adjustment, is very simple. For large earthquakes the method of recording shown in fig. 5 will probably be found suitable. A light pointer *l* is forked so as to enclose the hanging bar, and is jointed to the bob at its centre. Its end *m* rests on a smoked-glass plate, the pressure being regulated by a counterpoise *n*. The plate should be set in rotation by an earthquake, by means of a seismoscope which may conveniently be somewhat wanting in sensibility, in order that it may act only when the motion becomes tolerably severe. The record will be *less* than the true motion, in the ratio given above.

Fig. 6 shows an instrument of the same kind in plan, but with a multiplying index *p*, which is pivotted to the ground on a vertical axis *o*, and receives its motion by having a bent-up end which gears into a slotted plate *q* fixed to the bob.

Fig. 7 is a sketch of a curious form of double-freedom seismometer, in which a somewhat similar method of suspension is used. The base *S*, which is fixed, is an equilateral triangle, at the corners of which there are three conical cups

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forming sockets for three legs *r r r* of equal length. These legs press up into three other sockets in the plate, *s*, which are placed so as to form an equilateral triangle of half the linear dimensions of the base. The height of *s* from the base is 0.866 times the distance between the base sockets. The plate *s* carries a massive bob *w*, slightly beneath it. The plate is then in nearly neutral (somewhat stable) equilibrium with respect to small motions in any azimuth. It is necessary here to invert the system and use struts instead of ties, since a plate hung by three crossed cords would be azimuthally unstable. Two of the legs are made with loops to allow the three to cross each other. By adding a multiplying pointer to record the displacements of the base with respect to the centre of the plate, we should obtain a compact form of double-freedom seismograph, whose frictional resistance (though much greater than that of the single-freedom instrument just described) could probably be kept within reasonable limits.

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NOTE ON THE BALL AND CUP SEISMOGRAPH.

BY

T. ALEXANDER. C.E.
IMPERIAL COLLAGE OF ENGINEERING, TOKIO.

[READ JUNE 1ST 1883]

At the last meeting, Prof. West exhibited a model and introduced to our notice an instrument on a novel principle.—The heavy mass was guided by link motions so as to move sensibly in a straight line through a considerable range. Prof. Milne thought that rubbing friction would be reduced by making the mass run with its plane under surface on large and light friction wheels.

I now call your attention to the arrangement shewn by the rough model on the table. Small segments of spheres stand in spherical cups of half their curvature. They are three in number. Each is surmounted by a symmetrical upright spike terminating at the extremity of the diameter opposite to the central point of the segment, so that, when the segments roll in the cups the ends of the spikes move in a plane, a horizontal plane if the spikes be placed upright when the segment is at the bottom of the cup. The instrument is to be adjusted, by placing the plate containing the cups roughly horizontal, then putting one of the segments in its cup with the spike upright and placing a cupshaped weight on the top, the spike is to be screwed out till it just topples, when the spike is to be screwed in slightly to give a little stability. Each having been separately adjusted, a platform is placed over the spikes and loaded. The weight ought to rest on springs between it and the platform to prevent the balls from being made to jump in the cups by vertical shocks. The weight ought to be annular to resist rotating in the horizontal plan. The platform, also circular, should be concentri-

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cally situated in a circular hole in a rigid platform continuous with the under plate. The upper surfaces of this rigid platform and of the loaded platform are to be flush. A light pantagraph is to have a point fixed on the rigid platform and one moving point, being attached to the centre of the loaded platform, the other moving point will draw its path magnified on the rigid platform.

The instrument may be modified, by having two parts of cylinders rolling in cylindrical cups in lower fixed plate, each with too spikes or one knife edge. On the four spikes or two knife edges rests a platform with two cylindrical cups at right angles, in which parts of cylinders roll on whose spikes or knife edges the loaded platform rests.

If segments of spheres rolling on a plane with spikes terminating at their centres be used, the plane must be accurately levelled and there is also a danger of the whole sliding sideways under the horizontal shock.

The extremities of the spikes in the model shewn may be looked on as spheres of infinite curvature surmounted by cups. This suggests that, for a prolate spheroid standing upright in cups on a lower plate and surmounted by cups in an upper plate, horizontal motion or a slight degree of stability may be obtained by calculating suitable forms for those cups. Prof. Milne thinks this last arrangement suitable for a small earthquake house. The eggshaped boulders to be of hard stone and roll in cups above and below also wrought in stone. The absolute curvature of these cups ought to be sufficient that the boulders may not start out.

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CATALOGUE OF EARTHQUAKES FELT IN TOKIO BETWEEN JAN. 1882 AND MARCH 1883.

THE OBSERVATIONS WERE MADE AT THE METEOROLOGICAL OBSERVATORY (CHIRI KIOKU) BY PALMIERI'S SEISMOGRAPH.

(For the first portion of this Catalogue see Transactions of Seismological Society of Japan. Vol. II pages 3. and 39.)

1882

No.	Month	Day	Time			Force	Direction	Duration
			h	m	s			
430..	I	2	5	47	26	20′ 10′ 30′	WNW or ESE WSW or ENE SSE or NNW	16ˢ
431..	,,	14	7	34	17	0° 10′ 0° 10′	WNW or ESE WSW or ENE	....
432..	,,	25	3	47	27	....	.....	50ˢ
433..	,,	28	12	06	00	0° 10′ 1° 20′ 0° 20′ 0° 30′	WNW or ESE WSW or ENE SSW or NNE SSE or NNW	17ˢ
434..	II	5	17	00	30	0 10′ 1° 00′	SSW or NNE SSE or NNW	
435..	,,	12	2	49	00	0 10′	SSE or NNW	53ˢ
436..	,,	15	after 20 00 00			....	.....	....
437..	,,	16	5	33	13	1° 00′	WSW or ENE	45ˢ
438..	,,	18	5	52	00?	....	.....	....
439..	,,	,,	11	54	00?	0° 20′ 0° 10′	WSW or ENE SSW or NNE	1ᵐ 08ˢ
440..	,,	22	6	54	00	....	.....	20ˢ
441..	,,	28	13	49	40	1° 00′ 0° 10′	WSW or ENE SSE or NNW	11ˢ
442..	,,	,,	15	28	10	6° 40′ 1° 10′ 2° 00′	WSW or ENE SSW or NNE SSE or NNW	32ˢ
443..	,,	,,	15	33	00	....	.....	....
444..	III	1	about 2	07	00	....	.....	....
445 .	,,	7	11	05	56	0° 10′ 1 30′ 0 50′ 1 50′	WNW or ESE WSW or ENE SSW or NNE SSE or NNW	40ˢ
446..	,,	8	4	15	07	1° 20′ 0° 05′ 0° 50′	WSW or ENE SSW or NNE SSE or NNW	1ᵐ 20ˢ

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1882

No.	Month	Day	Time	Force	Direction	Duration
447..	,,	,,	about 11 54 50	0° 30′ 0° 20′	WSW or ENE SSW or NNE	38ˢ
448..	,,	,,	about 11 56 48	...	.....	22ˢ
449..	,,	11	about 7 50 54	2 30′ 11 20′ 9 50′ 9 00′	WNW or ESE WSW or ENE SSW or NNE SSE or NNW	8ᵐ 20ˢ
450..	,,	18	9 20 00	....	.....	....
451..	,,	14	21 48 52 23 57 42	....	....	....
452..	,,	18	21 25 33	2° 00′ 0 40′ 1° 10′	WSW or ENE SSW or NNE SSE or NNW	21ˢ
453..	,,	24	4 36 21	0° 20′ 0. 20′ 0. 10′	WNW or ESE WSW or ENE SSW or NNE	35ˢ
454..						
455..	,,	31	3 19 53	0 10′	SSE or NNW	9ˢ
456..	IV	2	4 48 51	0° 10′ 2° 40′ 2° 00′ 1° 10′	WNW or ESE WSW or ENE SSW or NNE SSE or NNW	44ˢ
457..	,,	4	6 34 47	....	.....	....
458..	,,	7	17 12 37	0 20′	WNW or ESE	....
459..	,,	8	3 21 00	....	.....	....
460..	,,	9	3 19 27	0 10′ 0 20′ 0 10′ 0 20′	WNW or ESE WSW or ENE SSW or NNE SSE or NNW	1ᵐ 48ˢ
461..	,,	25	about 8 33 30	0 10′	SSE or NNW	30ˢ
462..	V	2	5 21 00	....	.....	....
463..	,,	,,	22 58 27	....	.....	....
464..	,,	16	18 50 40	....	.....	....
465..	VI	7	2 26 41	0. 20′ 0. 20′ 0. 40′	WNW or ESE WSW or ENE SSE or NNW	19ˢ
466..	,,	14	10 05 38	0. 10′ 0. 20′	SSW or NNE SSE or NNW	40ˢ
467..	VII	10	about 11 24 00	....	.....	....
468..	,,	25	1 14 00	0° 50′	SSW or NNE	....
469..	VIII	18	5 34 20	...	.....	about
470..	IX	28	17 17 33	1° 20′	SSE or NNW	1ᵐ 00ˢ
471..	X	3	22 48 00	0° 10′ 0° 10′ 1° 30′	WNW or ESE SSW or NNE SSE or NNW	14ˢ
472..	,,	8	17 45 43	0° 30′	SSE or NNW	....
473..	,,	19	15 10 37	3° 40′	SSE or NNW	....
474..	,,	25	6 55 00	....	.....	....
475..	XI	4	22 45 43	....	.....	24ˢ

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1883

No.	Month	Day	Time	Force	Direction	Duration
476..	I	12	2 43 53	....	.....	0m 20s
477..	,,	14	3 42 50	....	.....	....
478..	,,	17	16 40 05	5° 30′ 10° 50′ 12° 10′ 6° 50′	N or S NW or SE W or E SW or NE	0m 40s
489..	,,	21	about 12 20 00	2° 50′ 6° 00′ 0° 10′ 5° 10′	N or S NW or SE W or E SW or NE	....
480..	,,	31	0 17 00	0° 30′ 3° 10′ 3° 00′ 4° 00′	N or S NW or SE W or E SW or NE	....
481..	,,	,,	1 9 14	2° 50′ 4° 00′ 1° 40′ 0° 30′	N or S NW or SE W or E SW or NE	0m 13s
482..	III	8	about 22 28 00	1° 10′ 0° 20′	W or E SW or NE	....
483..	,,	13	16 35 38	0° 30′ 0° 20′ 1° 00′	N or S W or E SW or NE	0m 8s
484..	III	14	19 57 02	0° 50′	SW or NE	....
485..	IV	20	9 57 10	0° 30′ 1° 10′ 2° 00′	N or S NW or SE SW or NE	1m 00s
486..	,,	23	10 32 50	8° 50′ 3° 10′ 11° 10′ 10° 10′	N or S NW or SE W or E SW or NE	1m 15s
487..	,,	,,	10 41 20	....	.....	0m 30s
488..	V	2	5 17 06	1° 30′ 1° 50′ 3° 30′ 2° 00′	N or S NW or SE W or E SW or NE	0m 20s
499..	,,	6	about 6 00 00	....	.....	....
490..	,,	12	13 18 23	0° 10′ 0° 10′ 3° 30′	N or S NW or SE W or E	....
491..	,,	3	5 58 52	1° 00′ 1° 10′ 1° 20′ 0° 30′	N or S NW or SE W or E SW or NE	about 1m 00s about 1m 00s
492..	,,	28	1 15 10	....	.....	
493..	,,	29	6 07 02	0° 10′ 0° 50′ 1° 50′ 0° 40′	N or S NW or SE W or E SW or NE	0m 21s

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1883

No.	Month	Day	Time	Force	Direction	Duration
494..	VI	10	10 15 00	18° 20′ 14° 10′ 11° 10′ 11° 00′	N or S NW or SE W or E SW or NE	about 1m 10s
495..	,,	12	about 6 18 00	....	.....	about 1m 00
496..	VII	18	8 44 00	....	.....	....
497..	,,	18	about 8 50 00	....	.....	.. .

Observations ceased on the 5th November 1882, and were not continued until the end of December when the instrument had been put up at the new station in the castle grounds, about a mile from the old station.

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REPORT OF THE COMMITTEE ON A SYSTEM OF EARTHQUAKE OBSERVATIONS.

[READ AND DISCUSSED JUNE 1ST 1883.]

One of the main objects of the Seismological Society from the commencement was to invoke as soon as possible the assistance of the Imperial Japanese Government in carrying out a system of observations after a definite plan, as it was evident that one of the first aims of seismometry, the location of centres or lines of disturbance, could not be arrived at without such aid.

Hitherto this assistance has not been nor could have been asked for, by the Seismological Society, on account of the difficulties and doubts attending the adoption of any one instrument for a number of stations. Many instruments have been constructed and tried by our members and have given indications, but whether and how far the latter are reliable, has not been thoroughly tested yet. Dr. Wagener, who pointed out the necessity of such a test, formulated the same as follows: If two instruments built on exactly the same principle, but differing in size, in the proportion of the various parts and in azimuth, while being set up near to each other, give for the same earthquake the same indications, there is good reason to believe that such instrument is reliable.

This test has to the best of our knowledge not yet been applied, and thus, while acknowledging that great ingenuity has been displayed by several members in inventing new and improving old instruments, the Committee is nevertheless of the opinion, taking into consideration the cost, the simplicity of observation and the experience gained hitherto, that the only observations which can at present be safely recommended for a number of stations and which can be made independent of the above test, are those of "Time" only, at the Telegraph Offices; namely, that time of an earthquake when the motion of the earth reaches a certain amplitude.

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The objection that may be urged against this plan is that the times when the vibrations reach a certain definite amplitude, even supposing this could be accurately observed, may not refer to the same wave or phase of the earthquake vibration. Your Committee frankly acknowledge this to be true, but claim that this time of reaching a certain definite amplitude is the only definite time that can be observed by simple apparatus, and that this method offers the readiest means of determining the center or line of disturbance and the average velocity of transmission of this disturbance through the ground, and therefore offer of the following—

RECOMMENDATIONS

AS TO PLAN OF SEISMOLOGICAL OBSERVATION.

1. Observations, at different places throughout Japan, of the instants at which the ground reaches a certain amplitude of vibration.

2. Establishment of at least 10 stations at some selected telegraph offices, fitted with simple apparatus.

3. At each of these stations a post should be set firmly in the ground, and on the post should be mounted a clock and some arrangement for stopping it at the instant the motion of the ground reaches a certain amplitude of vibration.

4. These stations should be in a room of the telegraph offices so that the clock can be compared each noon with the signals which are sent simultaneously over all the telegraph lines.

5. The clocks should have second-hands, wooden pendulum rods, the pendulum $\frac{1}{2}$, $\frac{3}{4}$ or $\frac{3}{4}$ second, and, if they are wound every day, their daily rates should never differ by more than 1^s from a uniform daily rate for one week. They must have a maintaining spring to keep them going while winding. They should be thoroughly examined before purchasing, both for uniformity of rate extending over at least 10 periods of winding, and also for periodic errors which complete their cycle while the clock runs down once, and also for periodic error in the reading of the second-hand. Clocks which are

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wound daily would, on the whole, probably be the most satisfactory.

6. The arrangement for stopping the pendulum should do this with as little shock as possible, and so as to cause no torsion on the suspending spring.

7. Since it will be perhaps impossible on account of the cost to provide each station with a second clock (for comparison if the first one is stopped and afterwards set going again) and also difficult to provide other signals than the regular noon signal, only one accurate time observation will be possible in 24 hours; but this will be sufficient for a commencement, and experience will show whether it is more advisable afterwards to give the first 10 stations a second clock or to increase the number of stations.

8. Observation books to be provided for the telegraph operators, in which they should enter in duplicate all the regular daily comparisons of clocks with the noon signal, and one of these sets should be weekly torn out and sent by mail to the Seismological Society. By this method the Society can keep a close watch upon the performance of the clocks. Separate books should also be provided in which to enter, also in duplicate, the records whenever the clock is stopped by any cause whatever. These records should comprise the reading of the clock face when found stopped, this to the nearest ½ second; the time by a second clock (whole minute) when the first clock is started again and then the comparison of the two clocks with each other to the nearest half second; and any remarks as to intensity of shock, etc., if the observer noticed it. One of these records should be immediately torn out and sent by mail to the Seismological Society as soon as the record is completed.

[Here it is assumed that the telegraph office is provided with two good clocks like that described above, one to be kept going all the time, and the other fitted with the apparatus to stop it at the time of an earthquake. At stations thus provided with two clocks, they should both be compared daily with the noon signals]

9. The Seismological Society should appoint a permanent

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committee to receive and thoroughly discuss these records when sent in, and from time to time prepare reports embodying the results of these observations and their discussion, these reports to be printed in the Transactions of the Seismological Society.

If the Society approve of the above recommendations for this class of observations, the committee recommend the appointment of a committee of two foreign and two Japanese members of the Society, to make the following examinations and investigations, and report to the Society as soon as possible:

1. To see whether the Telegraph Department will co-operate with the Society to the extent indicated in the above recommendations, and to ascertain the location of suitable offices, what kind of clocks they are furnished with, whether it will be possible to mount the necessary apparatus in one of these rooms, etc.

2. To ascertain if clocks which will satisfy the conditions specified above can be purchased either in Tokio or Yokohama, what such clocks will cost, and whether they can be obtained for one month's trial at an astronomical observatory, with the option of purchasing them or not to depend upon the results of the one month's examination.

3. To examine the different forms of apparatus for stopping a clock when a vibration of the ground occurs, and select the one which seems best adapted to the purpose, and also decide upon what degree of sensitiveness it seems best to give the apparatus, and how much such an attachment will cost.

4. To ascertain the probable cost of an accurate determination of the latitudes and longitudes of the different stations, and also the probable degree of accuracy of the present maps or determinations already available.

E. KNIPPING.
H. M. PAUL.

Note. A long discussion followed the reading of this report. The respective advantages of employing a clock from which the time could be automatically recorded without stopping the same, as compared with a clock which was stopped, were considered. Suggestions were made as to the advisability of employing some simple seismograph in conjunction with the clock. The plan adopted by the society will appear in a subsequent report.

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ANNUAL REPORTS OF THE COMMITTEE OF THE SEISMOLOGICAL SOCIETY OF JAPAN.

The Seismological Society of Japan was established at a meeting of many of the residents in Tokio and Yokohama, held at the Tokio University on March 11th 1880. At this Meeting General T. B. Van Buren, U. S. Consul General, whose efforts had a considerable influence in the formation of the society, took the chair. A full report of this meeting may be found in the Japan Gazette of March 12th 1880. The work which has been accomplished by the society since this time, is briefly indicated in the following reports and in the six volumes of Transactions which have been published.

SECRETARY'S REPORT.—MARCH 23RD—1881.

The Committee have the pleasure of presenting the following report.

The Society was organized at a meeting held at the Tokio Daigaku March 11th 1880, and since that time has held regular monthly meetings except during the vacatien months in summer.

The number and character of the papers read before the Society have been such as to show the necessity and benefit of united action among students of seismology in Japan. Thus far the papers presented have all been in the English language. The committee are glad to state that papers in Japanese have been promised for the coming year.

The list of members has steadily increased since the foundation of the Society, the few who have resigned having nearly all done so because they were leaving, or soon to leave the country. It seems advisable to create a class of corresponding members, so that those who wish may keep up their connection with the Society after they have left Japan.

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The Committee regret that the printing of the Proceedings of the Society has not been as expeditious as they have desired. It was at first debated whether to expend the funds of the Society in publishing papers, or in encouraging and extending seismological observations. The question was decided by the kind offer of the proprietors of the Japan Gazette to print the Proceedings on terms which were very advantageous to the Society. We have been notified that they will be unable to continue this arrangement, so that for the next year the expense of printing which is by far the largest item of our expenditures will fall upon the Society. It is hoped that, with the balance from this year, the income of the next year will enable the Society to print all papers which may be offered.

The Committee wish to call the attention of the Society to the considerable number of Japanese gentlemen who have joined the Society. Believing that, if the Society is to continue for many years, it must depend mainly upon Japanese members for its support, the Committee recommend that timely action be taken by the Society to excite an interest among Japanese scholars in seismology and induce them to join the Society. The Committee would also recommend the publication of a pamphlet in the Japanese language giving an introduction to observational seismology for circulation throughout the country.

During the year a considerable number of machines for recording and measuring earthquakes, all of them the inventions of members, have been exhibited and described before the Society, and a number of them are now in operation. Early in the session a motion was passed that a committee should be appointed to examine each and every machine that was presented to the Society. In accordance with this motion one committee was appointed; but it has not yet reported. It is to be hoped that this resolution may be put in force.

A request has been made to this committee from the University of Tokio to recommend a machine suitable for general use in Japan. The committee desire the reports spoken

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of, so that they may be able to fulfil this request and similar ones in the future. The committee recommend the appointment of a *single* committee who shall examine and report on all the machines which have been submitted to the Society.

We add below, the Treasurer's report which has been audited by Professors Gray and Milne; a list of the papers and notes read before the society; and a list of the present members of the society.

In conclusion, the committee congratulate the Society on its success during the first year of its work; on the great advances which, through the researches of its members, have been made in the knowledge of seismology; and on the interest which its labors have excited among scientific men in other lands.

W. S. CHAPLIN.

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Treasurer's Report 1880—1881.

Dr.

To Stationery & Printing of Postal Cards etc....		Yen	16.95
„ Heating		„	1.20
„ Advertisements	$ 10.00		
„ Cost of Lithographs		„	89.42.9
„ „ „ Observation Books ...		„	32.32
„ Exchange	„ 22.37		
„ Balance	„ 252.63		
	$ 285.00	& Yen	139.89.9

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By Subscriptions			
from 57 members at $ 5.00.....	$ 285.00		
„ 8 „ „ Yen 6.72.5			
to Yen 8.30		Yen	55.97.5
„ Contributions from authors to			
cost of Lithographs		„	44.71.3
„ Exchange of $ 22.37 at Yen 1.75.		„	39.21.1
	$ 285.00	& Yen	139.89.9

Note:—All Subscriptions paid to Dec. 31st 1880.

One liability, not yet determined in amount, for one volume of Transactions, approximately $ 50.00.

Credit Dependency: Balance as above $ 252.63.

P. MAYET.

Tokio March 19th 1881. *Hon Treasurer.*

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Secretary's Report March 23rd—1882.

During the last year the Society has been quite as prosperous as was expected; the number of members has steadily increased; the funds of the society are in a prosperous condition; and its labors are attracting considerable attention in the scientific world.

Among the agreeable features of this year's work has been the correspondence with the Authorities of the Philippine Islands. The Governor General of those islands, seeing the necessity of studying the phenomena which caused such terrible destruction in Manila, has instituted a special bureau, under the direction of the Inspector General of Mines, with the object of collecting information with regard to earthquakes in the Philippines and other countries. Mr. Abella y Casariego has kindly sent to this society two papers, one of which, written by himself, has already been read, and the other is now being translated and will be presented at an early meeting.

In England Prof. Judd F.R.S. has brought this society to the notice of the Geological Society of London; and in America, Prof. Mendenhall has secured a large number of members.

The second volume of the Society's Transactions has been printed and circulated; the third volume is now in the press at the Insatskioku; and the fourth volume is being printed as rapidly as the papers are read, at the office of the Japan Mail in Yokohama.

The first edition of the Observation-books having been exhausted, it was necessary to print a second one; and advantage has been taken of this opportunity to introduce the Japanese equivalents for the English words in the forms, so that the books can be used by persons who are only acquainted with the Japanese language. About one hundred reports have thus far been received these will be tabulated and published in the transactions.

The Report of the Treasurer showing a balance of $ 133.83 and yen 652.47, and a list of the papers read before the Society during the last year are appended.

W. S. CHAPLIN.

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Treasurer's Report.—1882.

The Balance brought forward from the first year amounted to $ 252.63. The Income of this year amounted to $ 81.20 and Yen 728, being the result of 106 subscriptions and of a gain by exchange made on 11 subscriptions paid in the United States. The Total of the Society's Income in cash was therefore $ 333.83 and Yen 728.

The Expenditures amounted to $ 210 and Yen 195.53 for printing, translation of a paper, Seismological Exhibition, postage etc.

The Balance to be carried over to next year, amounts therefore to $ 123.83 and Yen 532.47. The sum kept in Dollars is deposited with the Hongkong and Shanghai Banking Corporation, and the sum kept in Paper yen it is intended to deposit with the Imperial Japanese Postal Saving's bank, so that an interest of 7½ per cent may accrue on it.

All arrears of last year have been collected as well as paid.

The arrears of the year 1881-2 consist of 17 Subscriptions, due, but not yet paid, part of them having to be colleeted from abroad or outside Yokohama and Tokio, amounting together to $ 10. and Yen 120.

The Total of Credit Dependencies, bank-deposit cash and arrears together, to be carried over, amounts therefore to $133.83 and Yen 652.47.

While having the honor of handing in my account and the youchers, I cannot conclude without tendering my best thanks for the kind assistance in collecting the subscriptions I received from Prof. Mendenhall in the United States, Mr. Holtham in Kobe, Messrs Pryer and Bisset in Yokohama, and Mr. Hattori in Tokio.

P. MAYET:
Hon. Treasurer.

Tokio. 23th of March 1882.

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Secretary's Report. April 27th, 1883.

The Secretary of the Seismological Society of Japan has pleasure in presenting the following, as a report on the work done by the Society during the past year.

Since the election of the present officers of the Society in March 23rd 1882, four general meetings have been held.

At these meetings papers were read which have been published as Volume V of the Transactions of the Society. One paper was published in Spanish and another was translated from the Spanish original. The publication of Vols. III and IV was also accomplished during the year.

Arrangements have been made to have abstracts prepared of all the papers hitherto published in Japanese and to be printed as a portion of the Japanese Transactions of the Society.

Arrangements have also been made, by the appointment of a special committee, for the examination of the numerous notices of Earthquakes which the Society has from time to time received, principally from those to whom observation books had been distributed. The results of this examination will be published.

During the past year several interesting papers in Seismology have been received from Manila. These may be regarded not only as valuable contributions to the Transactions of the Seismological Society, but also as testimonies of appriciation of the Society's work.

In order to engage the interest and cooperation of other nationalities in Seismological investigation the Committee have distributed copies of the Transactions of the Society to the leading Societies, Academies and Seismologists, in various parts of the world.

In many instances there gifts have been acknowledged not only by receipts, but by exchanges

In conclusion the Committee congratulate the Society on the interest which has been shown in its work by various foreign journals, testifying to the advances in Seismology reached by its labours.

JOHN MILNE.

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LIST OF PRESENTS RECEIVED.

NOTE. THIS LIST IS INCLUSIVE OF ALL PRESENTS UP TO NOV. 8TH 1883.

Abella y Casariego, Don E.—Memoria acerca de los criaderos aurifer os del departmento de Mindanao. Madrid 1879.

Centeno y Garcia, Don J.—Memoria Geologicominera de las Islas Filipinas. Madrid 1876.

Memoirs of the Science Dept. of the University of Tokio:—

No 6—*Atkinson, R. W.*—The Chemistry of Saké—Brewing, Tokio 1881.

No 7—*Mendenhall, T. C.*—The Meteorology of Tokio for the Year 1880. Tokio 1881.

No 8—*Mendenhall, T. C.*—The wave Lengths of some of the Principal Lines of the Solar Spectrum. Tokio 1881.

Proceedings of the Royal Soc. of Edinburgh, Session 1880—81.

General Catalogue of Dartmouth College, Hanover N. H. 1880,

Johns Hopkins University Circulars Vol. II Nos. 19 20.21.22 & 24.

Scientific Proceedings of the Ohio Mechanics Institute Vol. I No. 1.2.3. and Vol. II Nos 1.2.

Proceedings of the California Academy of Sciences:—containing—*Harkness, H. W.*—Footprints found at the Carson State Prison.

Le Conte, J.—Certain Remarkable Tracks found in the Rocks of Carson Quarry.

Gibbes, C. D.—Fossil Jaw of a Mammoth.

Leopoldina. Organ der K. Leop. Carol. deutschen Akademie der Naturforscher. Heft 18 Jar. 1882. Halle 1882.

Geinitz, E.—Das Erdbeben von Iquique am 9 Mai 1877, &c.

Bolletino del R. Comitato Geologico d'Italia 1882 Anno XIII Roma 1882.

Observaciones Verificadas del Observatorio Meteorologico del Ateneo Municipal de Manila 1879 Nov. and Dec. Manila. 1880, 1881, 1882, 1883.

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Société de Géographie, Compte Rendue 1883 No. 5 10. 11. 12. 13 & 14.

Dechevrens, le P. Marc, S. J., La Lumière Zodiacale. Zikawei 1879.

„ On the Storms of the China seas, &c. Zikawei 1880.

„ The Typhoons of the China seas in the year 1881. Zikawei.

„ Sur l'Inclinaison des Vents, &c. Zikawei 1881.

„ Le Magnétisme Terrestre à Zikawei, Chine. Zikawei 1881

„ Le Typhoon du 31 Juillet 1879. Zikawei 1879.

„ The Climate of Shanghai, Its Meteorolog. Condition (extract from Transactions).

Zeitschrift der Österreichischen Gesellschaft für Meteorologie XVIII Bd., Jän.—Feb.—Mär.—Apr.

Bulletin Meusuel de l'Observatoire Magn: & Meteor: de Zikawei. T. VIII, Ann. 1882.

Catalogue and announcements of the University of Pennsylvania.

Calendar of the University of Michigan,

Papers from the American Journal of Science.

Prof C. G. Rockwood Vol. XXIII Jan. 1882 Volcanoes, what they are and what they teach (Review). Oct. 1881. Notes on Earthquakes.

„ Vol. XXI March 1881. Notices of recent American Earthquakes. Nos 10.

„ Vol. XXII Dec. 1881 Japanese Seismology.

Jahrbücher der K.K. Central-Anstalt für Meteorologie und Erd Magnetismus Part I 1879.

F. Sandberger. Ueber den Basalt von Naurod bei Wiesbaden and seine Einschlüsse.

Dr. F. Hochstetter. Ueber Erdbeben mit Bezieung auf das Agramer Erdbeben vom 9 November 1880.

Transactions of the Connecticut Academy of arts & sciences Vol. V Pt. 1 & 2.

The Yorkshire College Leeds. Annual Report 1882-3.

Proceedings of the Canadian Institute Toronto. Vol. I F 4.

Atti della R Accademia dei Lincei Vol. VII Pts. 1-10.

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Tableau diverses Vitesses.

Publicationen des Astrophysikalischen Observatoriums zu Potsdam. Band III.

Bulletin de la Société de Géographie 1er Trimestre 1883.

Journal of the Royal United Service Institution Nos. CXIX, CXX and appendix. 1883.

Prof: Dr. R. Hoernes. Erdbeben in Steiermark während des Jahres 1880.

Prof. Dr. R. Hoerness. Die Veränderungen der Gebirge und ihre Beobachtung.

M. J. L. Soret. Sur les travaux de la commission seismologique suisse et sur les tremblements de terre récemment ressenis en Savoie.

Chales Soret. Le tremblement de terre du 22 Juillet 1881.

M. Daubrée. Descartes, l'un des créateurs de la cosmologie et de la géologie.

———Recherches expérimentales sur les cassures qui traversent l'écore terrestre, &c.

———Sur les réseaux de cassures on diaclases qui coupent la série des terrains stratifiés &c.

———Expériences Synthétiques relatives aux Météorités.

———Formation contemporaine de diverses espèces minérales crystallisées dans la source thermale de Bourbonne-les-Bains.

———Sur la relation des sources thermales de Plombières avec les filons metallifères &c.

———Association du Platine Nativ a des Roches &c.

———Essai d'une classification des cassures de divers ordres, que presénte l'écorce terrestre.

———Expériences sur la schistosité des roches et sur les deformations de fossils &c.

———Expériences relatives à la chaleur développée dans les roches par les actions méchaniques &c.

———Application de la méthode expérimentale à l'étude des déformations et des cassures terrestres.

———Expériences sur la possibilité d'une infiltration capillaire autravers des matières poreuses &c.

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SEISMOLOGICAL SOCIETY OF JAPAN.

CONSTITUTION.

[CORRECTED TO JUNE 7TH 1883.]

1.—This Society shall be called the *Seismological Society of Japan.*

2.—The objects of this Society shall be the furtherance of the study of, and the collection of facts relating to all the phenomena connected with *earthquakes* and *volcanoes.*

3.—At the meetings of the Society papers on general science may be read, subject to the approval of the Society.

4.—This Society shall consist of *Corporation, Honorary* and *Ordinary* members.

5.—*Honorary Members,* who must be non-residents in Japan, shall be admitted on grounds to be determined by the Committee.

6.— }
7.— } Cancelled.

8.—The annual subscription shall be due on January 1st, and shall be, for members who receive the English *Transactions,* 6 *yen,* or £ 1., or $ 5. Japanese members who live in the interior may receive only the Japanese *Transactions,* and in that case the annual subscription shall be 4 *yen.*

9.—The Officers of the Society shall be a *President,* a *Vice-President,* a *Foreign Secretary,* a *Japanese Secretary,* a *Foreign Treasurer,* a *Japanese Treasurer* and five *Ordinary Members,* two of whom shall be residents of Yokohama. These eleven shall form the Committee, of whom four shall form a quorum. The Chairman of the Committee shall have a deciding vote.

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10.—The affairs of this Society shall be managed by the Committee, who shall also decide on the papers to be published in the *Transactions* of the Society.

11.—General Meetings, due notice of which shall be given to the Members by the Secretary, shall be held at convenient dates in Tokio or Yokohama.

12.—The Officers of the Society shall be elected each year by ballot at an Annual Meeting.

13.—The Committee shall hold a Meeting one week before each General Meeting.

14.—At the Annual Meeting, the Secretary and the Treasurer shall present their Reports.

15.—Any amendments to this constitution may be proposed at any General Meeting, and shall be considered at the next, when, if two-thirds of the Members are present, it may be passed by a majority vote; if however two-thirds of the Members are *not* present, and the majority of those present are in favor of the amendment, it shall be considered at the succeeding Meeting, when, if a majority of those present are in favor of the amendment, it shall be adopted.

16.—The Secretary shall notify Members of proposed amendments to the constitution.

RULES ADOPTED BY THE COMMITTEE.

[Corrected to Jan. 1. 1883]

1.—Every paper shall be submitted to the Committee, either in full or abstract, before it is put on the list of the Society for public reading.

2.—Any person presenting a paper to the Society shall be required to state whether he intends to publish it elsewhere.

3.—Each paper shall be submitted to a sub-committee who shall have power to recommend whether it shall be printed in the *Transactions* of the Society *by title, in abstract,* or *in full.*

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4.—The printing, in the Society's *Transactions*, of remarks or criticisms upon papers read at any meeting, shall be limited substantially to what was uttered in public at such meeting; or if any new matter, in the way of further remarks or criticism, is offered later, it must first be submitted to the Committee for their decision.

5.—To any new Member of the Society will be given one copy of all the volumes of the *Transactions* published after such Member joins the Society, and to any retiring Member the volumes including the papers read up to the time of such Member's resignation, if all his dues are then paid.

6.—To Members of the Society extra copies of the *Transactions* will be sold at the cost price of publication, which may be learned by application to the Secretary.

OFFICERS OF THE SOCIETY.

FOR 1882—1883.

President—General G. Yamada, Minister of the Interior.
Vice-President—Dr. G. Wagener.
Foreign Secretary—Prof. John Milne.
Japanese Secretary—Prof. D. Kikuchi.
Foreign Treasurer—E. Knipping, Esq.
Japanese Treasurer—N. Kanda, Esq.

Members of the Committee,
- *Tokio*
  - I. Hattori, Esq.
  - Dr. E. Divers.
  - Dr. E. Naumann.
- *Yokohama*
  - Capt. F. Brinkley, R.A.
  - W. H. Talrot, Esq.

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MEMBERS OF THE SOCIETY.

[CORRECTED TO JUNE 7TH 1883].

Honorary Member.

HIS MAJESTY KING KALAKUA of the *Hawaiian Islands.*

Corporation Member.

The *Kayo Gakko*.....*Gifu Ken.*

Ordinary Members.

ABELLA Y CASARIEGO, DON ENRIQUE .....*Manila.*
ALEXANDER, PROF. T, C. E. .....*Tokio.*
ARAI, I. ..... „
BAELZ, PROF. E., M.-D. ..... „
BASSNET, THOMAS .....*Jacksonville, Fa., U. S. A.*
BASSNET, MRS. T. ..... „ „ „
BEADON, R. J. .....*Tokio.*
BEUKEMA, T. W., M. D. .....*Yokohama.*
BIAGIONI, F. ..... „
BISSET, J. ..... „
BLACKISTON, CAPT. T. W., R. A. ..... „
BOLTON, PROF. H. C. .....*Hartford, Conn., U. S. A.*
BRINKLEY, CAPT. F., R. A., EDITOR OF THE "JAPAN MAIL" .....*Tokio.*
BROWN, A. R. .....*London.*
BROWN, COLVILLE. ..... „
BROWNE, H. ST. JOHN. .....*Kobe.*
BRUSH, PROF. G. J. .....*New Haven, Conn., U. S. A.*
CARCANO, COUNT SILVIO, H. ITALIAN M. CONSUL .....*Yokohama.*
CASATI, LUIGI .....*Tokio.*
CHAMBERLAIN, B. H. ..... „
CHAMBERS, JOHN, C. E. ..... „
CHIOSSONE, E. ..... „
CONDER, JOSIAH. ..... „
COX, W. D. ..... „
COX, PROF. E. T. .....*San Francisco, Cal., U. S. A.*
DAN, T. .....*Tokio.*

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DIVERS, PROF. E., M. D. ..... *Tokio.*
DU BOIS, DR. F. ..... „
EYKMANN, DR. J. F. ..... „
ELDRIDGE, STUART, M. D. ..... *Yokohama.*
ELGAR, F. ..... *London.*
EWING, PROF. J. A. ..... *Tokio.*
FENOLLOSA, PROF. E. F. ..... „
FUJIOKA, PROF. J. ..... „
FUJITANI, T. ..... „
FUKUOKA, H. E. T., MINISTER OF EDUCATION ..... „
FURUICHI, K. ..... „
FUTAMI, K. ..... „
GORDON, T. W., M. D. ..... *Georgetown, Ohio, U. S. A.*
GOTO, M. ..... *Tokio.*
GOTTSCHE, PROF. C. ..... „
GOWLAND, W. ..... *Osaka.*
GRAY, PROF. THOMAS. ..... *Glasgow.*
HAMAO, A. ..... *Tokio.*
HARKNESS, PROF. WM., U.S.N. ..... *Washington, U. S. A.*
HATTORI, I. ..... *Tokio.*
HAWES, LIEUT. A. G. S., R. M. ..... „
HEGT, M. J. B. N. ..... *Yokohama.*
HOLTHAM, E. G., C. E. ..... *London.*
IRWIN, R. W. ..... *Tokio.*
ISAWA, S. ..... „
IWASA, PROF. I. ..... „
JAMES, LIEUT. J. M. ..... *Shinagawa.*
JUDD, PROF. J. W., F. R. S. ..... *School of Mines, London.*
KANDA, N. ..... *Tokio.*
KATAYAMA, T. ..... „
KATO, H., PRESIDENT OF TOKIO UNIVERSITY ..... „
KIKUCHI, PROF. D. ..... „
KNIPPING, E. ..... „
KOCHIBE, T. ..... „
KORSCHELT, O. ..... „
KOZIMA, PROF. N. ..... „
KUDO, S. ..... *Sapporo.*
KUKI, R., VICE-MINISTER OF EDUCATION ..... *Tokio.*

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KUWABARA, M. ..... *Bessi Copper Mine, Shikoku.*
LARRIEU, D. ..... *Tokio.*
LYMAN, B. S. ..... *Northampton, Mass., U. S. A.*
MCCARTHY, J. W. ..... *London.*
MARTIN-LANCIAREZ, E., H. ITALIAN M. CHARGÉ D'AFFAIRES... *Tokio.*
MAYET, P. ..... „
MENDENHALL, PROF. T. C. ..... *Columbus, Ohio, U. S. A.*
MILNE, PROF. JOHN ..... *Tokio.*
MIYAKE, PROF. H. ..... „
MORI, J. ..... „
NAKAMURA, K. ..... „
NAKASHIMA, N. ..... „
NAMURA, T. ..... *Chiugakko, Miyagi Ken.*
NAUMANN, DR. E. ..... *Tokio.*
NETTO, PROF. C. ..... „
NISHI, M. ..... „
OMORI, S. ..... „
OSBORNE, A. O. ..... *Waterville, N. Y., U. S. A.*
PALMER, LT.-COL. H. S., R. E. ..... *London.*
PARKES, H. E. SIR HARRY S., K. C. B., K. C. M. G., H. B. M. MINISTER, *Tokio.*
PATON, GEORGE ..... „
PAUL, PROF. H. M. ..... „
PRYER, H. ..... *Yokohama.*
RENNIE, SIR R. T., CHIEF JUSTICE OF H. B. M. SUPREME COURT FOR CHINA AND JAPAN .....
RINGER, F. ..... *Nagasaki.*
RODWELL, PROF. G. F. ..... *Wiltshire, England.*
RORETZ, A. VON, M. D. ..... *Yamagata.*
RUDLER, W. F. ..... *School of Mines, London.*
SATOW, E. M., 2ND SEC. AND JAPANESE SEC. OF H. B. M. LEGATION..... *Tokio.*
SEKIYA, K. ..... „
SHINAGAWA, Y., VICE-MINISTER OF AGRICULTURE AND COMMERCE ... „
SNOW, H. J. ..... *Yokohama.*
SUGI, K. ..... *Tokio.*
TALBOT, W. H., EDITOR OF THE "JAPAN GAZETTE" ..... *Yokohama.*
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TODA, W. ..... *Tokio.*
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TRANSACTIONS

OF THE

SEISMOLOGICAL SOCIETY OF JAPAN.

VOL. VII.

PART I.

1883—1884.

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EARTH TREMORS

BY

JOHN MILNE

[READ OCT. 25TH 1883.]

The object of the following paper on Earth Tremors is to bring to the notice of the members of the Seismological Society a study, which has hitherto received but little attention in this country. With the exception of a few brief references to a little work which I have personally undertaken, the paper does not claim any originality it being in the main a compilation of results obtained by observers in Europe.

The discovery of the existence of Earth tremors appears to have been accidental, rather than a result of inductive reasoning. No sooner had philosophers contrived astronomical and other instruments for the purpose of making refined measurements and observations than they at once discovered that they had an enemy to contend against in the form of microscopic earthquakes.

Artificially produced Tremors. Artificially produced Tremors exist in all our towns, and near a railway line they are perceptible with every passing train. Those who use microscopes of high power will readily appreciate how small a disturbance of the ground may be visible by the apparent movements which often take place in the object under examination. Captain Kater found that he could not perform his pendulum experiments in London on account of the vibrations produced by the rolling of carriages. Captain Denman who made some observations on artificially produced tremors found that of a goods train produced an effect 1100 feet distant in marshy ground over sandstone. Vertically however above a tunnel through the sandstone, the effects only extended 100 feet. A remarkable example of the trouble which artificially produced earth vibrations have occasioned those who make

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astronomical observations, occurred some 20 years ago at the Greenwich Observatory. When determining the collimation error of the transit circle by the reflexion of a star in a tray of mercury, it was found that on certain nights the surface of the mercury was in such of state of trembling that the observers were unable to complete their observations until long after midnight.

After obtaining a series of dates on which these disturbances occurred it was found that they coincided with public and bank holidays on which days crowds of the poorer classes of London flocked to Greenwich park where they amused themselves with running and rolling down the hill on which the Observatory is situated. On these occasions it was found that the disturbance in the Mercury was such that observations could not be made until 2 or 3 hours after the crowds had been turned out of the neighboring Park.

Whether we are to suppose that the hill continued to vibrate for this length of time after the cause of disturbance had been removed or whether it was due to the mercury continuing to oscillate in virtue of its inertia after having once been set in motion it is difficult to say (Palmer. Trans. Seis. Soc. of Japan III p. 148). To obviate this difficulty Sir George Airy suspended his dish of Mercury in a system of india rubber bands, and in this way succeeded in eating the intruders up.

Lieutenant Col H. S. Palmer R. E. when engaged with the transit of Venus expedition in New Zealand in 1874 was troubled with vibrations produced from a neighboring railway. To escape the enemy, he entrenched his instruments by placing them in pits. With pits 3½ feet deep he found himself sufficiently protected. The distance from the line was about 400 yards and the soil through which the disturbances were propagated was a coarse pebbly gravel (Trans. Seis. Soc. of Japan. III 148).

Before the United States Naval Observatory was established at Washington, Professor H. M. Paul was deputed to make a tremor survey to discover stable ground. The results of these experiments were exceedingly interesting. By watching the reflected image of a star in a dish of mercury a

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passing train would be noticed at the distance of a mile. Its approach could be detected by the trembling of the image before its coming could be heard. At one point of observation the disturbance appeared to be cut off by a ravine. The strata was gravel and clay (Paul. Trans: Seis: Soc: of Japan II p. 41). These few examples of artificially produced tremors, to which many more might be added, have been given because they teach us something respecting the nature of these disturbances.

Hitherto they have only been regarded as intruders which it was necessary to escape from or destroy. From what has been said they appear to be a superficial disturbance which is propagated to an enormous distance. This distance appears to depend upon the propagating medium, upon the intensity of the initial disturbance, and upon its duration. In the observation of these artificial disturbances which are accessible to every one, and which hitherto have been so neglected, we have undoubtedly a fruitful source of study.

Natural Tremors. Next let us turn to those microscopical disturbances of our soil which are due to natural causes. Thus far they seem to have been recorded wherever instruments suitable for there detection have been erected and it is not improbable that they are common to the surface of the whole globe.

Some of the more definite observations which have been made upon earth tremors were those made in connection with experiments on the deviation of the vertical due to the attractive influence of the moon and sun.

Prof. Zöllner who invented the horizontal pendulum which he used in the attempt to measure the change in level due to lunar and solar attraction, found his instrument so sensitive that the readings were always changing.

The most interesting observations which were made upon small disturbances of the soil were those of M. d'Abbadie who carried on his experiments at Abbadia, in Subernoa near Hendage 400 Meters distant from the Atlantic and 62 Meters above sea level. The soil was a loamy rock. Here M.

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d'Abbadie constructed a concrete cone 8 meters in height which was pierced down the center by a vertical hole or well which was continued, two meters below the cone into the solid rock. At the bottom of this hole or well, a pool of Mercury was formed, which reflected the image of cross wires placed at the top of the hole. These cross wires and their reflection were observed by means of a microscope. The observations consisted in noting the displacement and azimuth of the reflected image relatively to the real image of the wires. After allowing this structure 5 years to settle M. d'Abbadie commenced his observations. To find the surface of the mercury tranquil was a rare occurrence. Sometimes the mercury appeared to be in violent motion although both the air and neighboring sea were perfectly calm. At times the reflected image would disappear as if the mercury had been disturbed by a microscopic earthquake. The relative position of the images were in part governed by the state of the tide. Altogether the movements were so strange that M. d'Abbadie did not venture any speculations as to their cause but he remarks that the cause of the changes he observed were sometimes neither astronomical nor thermometrical. These observations the principal object of which was to determine changes in level rather than earth vibrations were carried on between the years 1868-1872. (G. H. and H. Darwin: Reports of British Association 1881).

Another instructive set of observations were those which were made in the years 1880-1882 by George and Horace Darwin at the Cavendish Laboratory at Cambridge. The main object in these experiments was to determine the disturbing influence of gravity produced by lunar attraction.

The result which was obtained however shewed that the soil at Cambridge was in such an incessant state of vibration that whatever pull the moon may have exerted upon the instrument which was employed, this was masked by the magnitude of the effects produced by the earth tremors, and the experiments had in consequence to be abandoned. The principle of this instrument was similar to an instrument devised by Sir William Thomson and put up by him in his

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Laboratory at Glasgow. As erected by the Darwins at Cambridge it was briefly as follows.

A pendulum which was a massive cylinder of pure copper was hung by a brass wire about a foot long inside a hollow cylindrical support rising from a stone support. A tiny galvanometer mirror was then hung by two fine threads, one of which was fastened to the bob and the other to the stone basement. A ray of light sent from a lamp on to the mirror was refrected to a scale 7 feet distant and by this means any motion of the bob relatively to the stone support was magnified 50,000 times. In several ways the apparatus was insulated from all accidental disturbances. The spot of light was observed from another room by means of a telescope. The instrument was so delicate that even at the distance of 16 feet the shifting of your weight from one foot to the other caused the spot of light to run along the scale. So sensitive was the instrument that notwithstanding its being cut off from the surrounding soil by a trench filled with water and the whole instrument being immersed in liquid to damp out the small vibrations it would seem that the ground was in a constant state of tremor, in fact so persistent and irregular were these movements that it seemed impossible to separate them from the movement due to the attraction of the moon. (Reports of British Association 1881).

As a result of observations like these the world gradually has had forced upon it the fact, that the ground on which we live is probably every where in what is practically an incessant state of vibration. The result of these observations has led those who were interested in the study of earth movements to establish special apparatus for the purpose of recording such motions with the hope that the laws by which they were governed might be discovered.

Instruments specially intented to record Earth Tremors.

The simpler forms of apparatus which have been used may be described as delicate forms of seismoscopes which in addition to being useful as recorders of earth tremors also record the occurrence of small earthquakes. A simple contrivance which may be used for the purpose of recording

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small earthquakes may be made with a small compass needle. This is deflected so far by the attractive influence of a piece of iron, that on the slightest shake its equilibrium is overcome and it flies to the iron where it remains until reset.

In Japan a large number of small earth disturbances have been recorded with crude apparatus of this description. Another form of apparatus employed in Japan has been a delicately constructed circuit closer. The motions of this instrument it was found might be recorded by means of an electric magnet deflecting a pencil which was tracing a circle on a revolving dial. The revolving dial was a disc of wood covered with paper fixed to the hour hand axle of a common clock.

A third form of apparatus used in Japan consisted of a small piece of sheet lead about the size of a three penny piece suspended by a short loop from a rigid support. Projecting from the lead a fine wire about 2^{in} in length passes freely through a hole in a metallic plate. By the slightest motion of the support the small pendulum of lead is set into a state of tremor and causes its pointer to come in contract with one or other side of the hole in the metal plate, by which it closes an electric circuit.

A more refined kind of apparatus which has been employed in Japan was similar to that used by the Darwins at Cambridge. This was so arranged that any deflection of the mirror was permanent until the instrument was reset and in this way the maximum disturbance which had taken place between each observation was recorded. In addition to these and other contrivances, experiments were made with microphones. Those which were first employed were the ordinary carbon microphones. They were fixed on the head of stakes driven in the ground at the bottom of pits. Another form of microphone which I employed consisted of an aluminium wire standing vertically on a metallic plate, its upper end passing loosely through a hole in an alluminium wire standard. The upper end of the vertical wire was loaded with lead. This contrivances possessed all the sensitiveness of an ordinary microphone whilst if it received a sudden impulse

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there was a sudden break in the current during the time that the vertical wire was being thrown across the hole in the standard. After many months of tiresome observation with instruments of this description and after eliminating all motions which might have been produced by accidental causes the general result obtained shewed that in Tokio there were microscopic movements of the soil to be detected every day and sometimes many times per day. (For a fuller account of these instruments see "Experiments in Observational Seismology." J. Milne. Trans: Seis. Soc. Vol. III p. 12.)

Work in Italy.

The most satisfactory observations upon microseismic disturbances are those which have been made during the last ten years in Italy.

The father of systematical microseismical research appears to have been Father Timoteo Bertelli of Florence. In 1870 Father Bertelli suspended a pendulum in a cellar which he observed with a microscope. As the result of his observations it was announced to the world that he had perceived the earthquakes which in 1870 shook Romagna although to the ordinary observer in Florence, these shakings had not been perceptible.

In 1873 Bertelli by means of microscopes fixed in several azimuths made 5500 observations on free pendulums. He also made observations on reflections from the surface of mercury.[1]

One result of these observations was to shew that microseismic motions increased with a fall of the barometer. Similar observations were made at Bologna by M. le Conte Malvasia and also by M. de Rossi near Rome. On Jan. 14th 15th and Feb. 25th these three observers at their respective stations, simultaneously observed great disturbances.

Similar investigations were made at Nice by M. le Baron Prost.

Although doubt was cast upon Bertelli's observations they appear to have been the origin of a series microseismical observations, a distinguished leader in which is Prof. M. S. de

(1) Compte Rendus 1875 Jan. to June p. 685.

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Rossi of Rome who in 1874 found that large earthquakes were almost always preceeded or accompanied with microseismical storms.

In 1878 Prof. Rossi worked upon these small disturbances with the assistance of the microphone and telephone and his first results were published by Prof. Palmieri. Many of Prof. Rossi's observations were made in the grotto di Roca de Papa, 700 meters above sea level and 18 meters under the soil. Here over 6000 observations were made by means of microscopes, on pendulums of different lengths suspended in tubes cut in the solid rock.

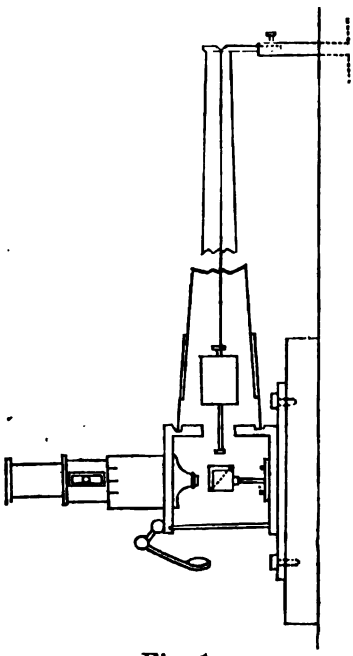

Fig. 1.

It is impossible to describe in detail the various forms of apparatus which have been used by the Italian investigators. A short description of one or two of the more important instruments may not however be out of place insomuch as they will assist the reader to understand the manner in which the various results respecting the laws governing microseismic movements, have been arrived at.

The most important of these instruments is the normal tromometer of Bertelli and Rossi. Fig. 1. This consists of a pendulum 1½ meters long carrying by means of a very fine wire a weight of 100 grammes. To the base of the bob, a vertical stile is attached and the whole is enclosed in a tube terminated at its base by a glass prism of such a form that when looked through horizontally, the motion of the stile can be seen in all azimuths. In front of this prism a microscope is arranged. Inside the microscope there is a scale so arrange

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that it can be turned to coincide with the apparent direction of oscillation of the point of the stile. In this way not only can the amplitude of the motion of the stile be measured but also its azimuth. The extent of vertical motion is measured by the up and down motion of the stile due to the elasticity of the supporting wire.

Another apparatus is the Microseismograph of Prof. Rossi. This is an arrangement to give automatic records of slight motions. It consists of four pendulums each about 3 ft long suspended so that they form the corners of a square platform. In the center of this platform a fifth but rather longer pendulum is suspended. The four pendulums are each connected just above their bobs to the central pendulum with loose silk threads. Fixed to the center of each of these threads and held vertically by light springs is a needle so adjusted that each thread is depressed to form an obtuse angle of about 155°. These needles form the termination of an electric circuit the other termination of which is a small cup of mercury placed just below the lower end of the needle.

By a horizontal swing of one of the pendulums this arrangement causes the needle to move vertically but with a multiplied amplitude. By this motion the needle comes in contact with the mercury and an electro-magnet with a lever and pencil is caused to make a mark on a band of paper moved by clock work.

The five pendulums being of different lengths allows the apparatus to respond "to seismic waves of different velocites."

Lastly we have Prof. Rossi's Microphone. This consists of a metallic swing arranged like the beam of a balance. By means of a movable weight at one end of the beam this is so adjusted that the other end of the beam falls down until it comes in contact with a metallic stop. This can be so adjusted that a slight tap will cause the beam to slightly jump from the stop. The beam and the stop form two poles of an electric circuit in which there is a telephone. The slightest motion in a *vertical* direction causes a fluctuation in the current passing between the stop and the beam and a consequent noise is

(See Tel Journ: Nov. 15th 1881.)

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heard in the telephone.

With instruments similar to these, observations have been made by various observers in all portions of Italy, extending over a period of 10 years.

Every precaution appears to have been taken to avoid accidental disturbances and the experiments have been repeated in a variety of forms. The results which from time to time have been announced are of the greatest interest to those who study the Physics of the Earth's crust and appear to be leading to the establishment of laws of scientific value.

It would seem that the soil of Italy is in incessant movement, there being periods of excessive activity usually lasting about 10 days. Such a period may be called a seismic storm. These storms are separated by periods of relative calms. These storms have their greater regularity in winter. Sharp maximums are to be observed in spring and autumn. In the midst of such a period or at its end, there is usually an earthquake. Usually these storms are closely related to barometric depressions. To distinguish these movements from those which occur under high pressure, they are called *baro-seismic* movements, the latter being called *volcano-seismic* movements. The relation of these storms to barometric fluctuation has been observed to have been very marked during the time of a volcanic eruption.

At the commencement of a storm the motions are usually small and one storm lasting 2 or 3 days may be joined to another storm. In such a case the action may be a local one. It has been observed that a barometrical depression tended to bring a storm to a maximum whilst an increase of pressure would cause it to disappear.

Sometimes these actions are purely local but at other times they may effect a considerable tract of land.

If a number of pendulums of different lengths are observed at the same place, there is a general similarity in their movements, but it is also evident that the free period of the pendulum more or less disturbs the character of the record. The greatest amplitude of motion in a set of pendulums is not reached simultaneously by all the pendulums, and at every

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disturbance the movement of one will predominate. From this Rossi argues that the character of the microseismical motions is not constant.

Bertelli observed that the direction of oscillation of the pendulums is different at different places but each place will have its particular direction dependent upon the direction of valleys and chains of mountains in the neighborhood. Rossi shews that the directions of movement are perpendicular to the direction of lines of faults, the lips of these fractures rising and falling, and producing two sets of waves one set parallel to the line of fracture and the other perpendicular to such a direction. These movements according to Bertelli have no connection with the wind, rain, change of temperature and atomospheric electricity.

The disturbances as recorded at different towns are not always strictly synchronous but succeed each other at short

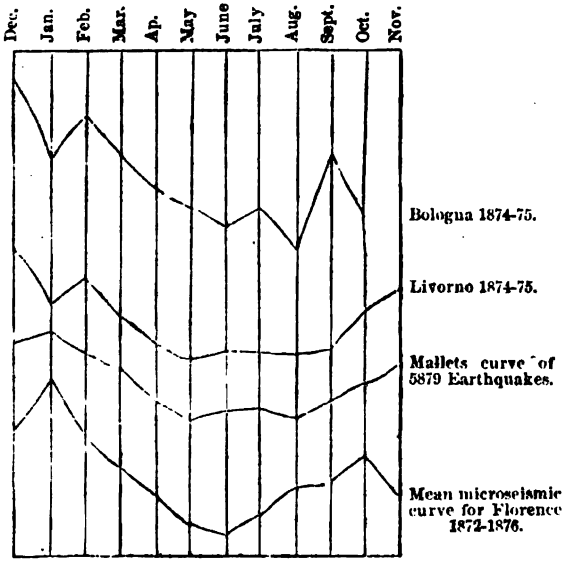

Fig. 2.

intervals. If however we take monthly curves of the disturbances as recorded at different towns in Italy we see that these are similar in character. The maximum disturbances occur

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about the winter solstice and the minimum about the summer solstice and in this respect they shew a perfect accordance with the curves drawn by Mallet to shew the periodicity of earthquake. The accompanying curves Fig. 2 taken from one of Bertelli's original memoirs, not only shew this general result but also shew the close accord there is between the results obtained at different towns during successive months.

At Florence before a period of earthquakes there is an increase in the amplitude and frequency of vertical movements. The vertical movements do not appear to come in with the horizontal barometrical disturbances but they appear to be connected with the seismic disturbances.

They are usually accompanied with noises in the telephone but as the microphone is so constructed as to be more sensitive to vertical motion than to horizontal motion this is to be expected. This vertical motion would appear to be a local action, insomuch as the accompanying motions of an earthquake which originates at a distance are horizontal.

Storms of microseismic motions appear to travel from point to point. Sometimes a local earthquake is not noticed on the Tromometer whilst one which occurred at a distance, although it may be small, is distinctly observed. To explain this Bertelli suggests the existence of points of interference and the existence of nodes. Similar results were arrived at by Rossi when experimenting at different points on the sides of Vesuvius. Galli noticed an augmentation in microseismic activity when the sun and moon are near the meridian. Grablovitz found from Bertelli's observations a maximum 2 or 3 days before the syzigies and a minimum 3 days after these periods. He also found that the principal large disturbances occurred in the middle of periods separating the quadrature from the syzigies, the apogee from perigee and the *lunistigi.* period from the nodes—whilst the smallest disturbances happened in the middle of periods opposed to these.

P. C. Melzi says that the curves of microseismic motions, earthquakes, lunar and solar motions shew a concordance with each other. With the microphone Rossi hears sounds which he describes as roarings, explosions occurring isolated

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or in volleys, metallic and bell like sounds, ticking &c. which he says revealed natural telluric phenomena. These are sometimes intolerably loud. At Vesuvius the vertical shocks corresponded with a sound like volleys of musketry whilst the undulating shocks gave the roaring. Some of these sounds could be imitated artificially, by rubbing together the conducting wires in the same manner in which the rocks must rub against each other in an earthquake, by placing the microphone on a vessel of boiling water, or by putting it on a marble slab and scratching and tapping the under side of it.

These then are some of the more important results which have been arrived at by the study of microseismic motions. One point which seems worthy of attention is that they appear to be more law abiding than their violent relations, the earthquakes, and as phenomena in which natural laws are to be traced they are certainly deserving of our attention. As to whether they will ever become the means of forewarning us against earthquakes is yet problematical. Their systematic study however will enable us to trace the progress of a microseismic storm from point to point and it is not impossible that we may yet be enabled to foretell where the storm may reach its climax as an earthquake. These I believe are the views of Prof. de Rossi who is at the present time engaged in the establishment of a system of microseismic observatories throughout Italy.

Before the earthquake of S. Remo on Dec. 6th 1874, Rossi's tronometer was in a state of agitation, and similar disturbances were observed at Livorno, Florence and Bologna. Since February 1883 I have observed a tronometer in Japan, and such results as have been obtained, accord with results obtained in Italy.

The increase in microseismical activity with a fall of the barometer is very marked. The stile of the pendulum does not always oscillate about the same point—there is a deflection of the vertical. In Manila, Father Faura also makes observations with a tromometer, which I am told gives him by its movements very decided indications of approaching typhoons.

As to the cause of tromometric movements we have a

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field for speculation. Possibly they may be due to slight vibratory motions produced in the soil by the bending and crackling of rocks produced by their rise upon the relief of atmospheric pressure. If this were so we should expect similar movements to be produced at the time of an increase of pressure.

Rossi suggests that they may be the result of an increased escape of vapour from the molten materials beneath the crust of the earth consequent upon a relief of external pressure. The similarity of some of the sounds which are heard with the microphone to those produced by boiling water are suggestive of this, and Rossi quotes instances where underground noises like those which we should expect to hear from a boiling fluid have been heard before earthquakes without the aid of microphones.

One instance was that of Viduare a prisoner in Lima who two days before the shock 1824 repeatedly predicted the same in consequence of the noises he heard.

A possible cause of disturbances of this order may be the sudden fluctuations in barometric pressure which are visible during a storm. During a small typhoon on Sept. 15th in 1881 when in the Kurile Islands I estimated that the needle of an aneroid for several hours worked back and forth with a period of from one to three seconds. At each gush of wind the needle suddenly rose and then immediately fell. At times it trembled. These movements were observed in the open air. The extent of these sudden variations were approximately from .03 to .05 inches. Reckoning an increase of barometric pressure of one hundredth of an inch as equivalent to a load of 20 million pounds on the square mile there must have been the equivalent of loads being continually placed on and removed from every square mile of from 60 to 100 millions of pounds. If the period of application of these stresses approximately coincided with the natural vibrational period of the area affected, it would surely seem, especially when we reflect upon the effect of an ordinary carriage, that tremors of considerable magnitude ought to be produced.

An inspection of the following observations taken from

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my note book for the same typhoon will suggest that even the larger and slower variations are capable of producing tremulous motions.

Time			Barometer
H.	M.		in.
12—	5	P. M.	29.02
12—	10		29.05
12—	12		29.07
12—	13		29.05
12—	25		29.10
12—	50		29.00
1—	10		29.00
1—	20		29.07

With these atmospheric disturbances not only do tronometers shew movements but the bulbs of delicate levels are in motion. Sometimes they appear to be surging backwards and forwards with an irregular period of from .5 to 2 or 3 seconds and an amplitude of from .25 to .5 of a millimeter. These movements together with those of pendulums apparently indicate a connection between atmospheric and telluric phenomena.

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THE EARTHQUAKES OF ISCHIA.

esuvius. Here we find Portici, Resina, Herculaneum,—names familiar to all readers. The north-west side of the bay extending from Naples to the island of Ischia presents us with an

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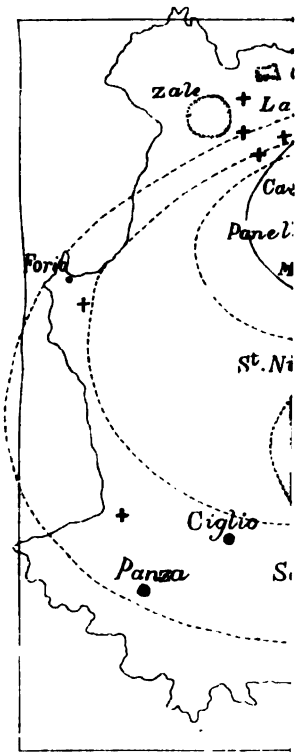
uninterrupted succession of volcanic phenomena, the Punta di Posilippo composed of volcanic tufa, the charming little island of Nisida an extinct crater, which however gave evidence



Scale $\frac{1}{80000}$, Isoseism
Old Craters

"miles. The total population of the island is about 25000." Distance from Naples 20 miles. The island is of purely volcanic origin and consists of one large central crater sur-

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rounded by a dozen parasitic ones and the accumulated product of its many eruptions.

The present island was originally submarine. This is evidenced by the presence of shells similar to those now found in the neighbouring sea at a considerable height upon its side.

The limits of the original submarine crater are approximately marked by the line of the road which surrounds Mount Epomeo.

The principal road of the island starts from the town of Ischia and makes the tour of the island back again to Ischia. There is a cross road from Castellamare to the neighbourhood of Barano. This cross road follows more or less exactly the lip of the old submarine crater. With the exception of the roads about Casamicciola and Lacco, these are the only roads on the island.

Let us make a tour of the island starting from Ischia northwards.

Almost immediately we come upon the Lava del Arso. This is the lava-current of 1302, the last eruption in the island. There is no crater properly speaking. The distance of La Cremate the point of issue, from the sea is 1½ miles. The eruption lasted 2 months. There is a spring (temp 93°) near here called **Acqua Pontano**.

Just beyond the lava current about 1 m. from Ischia is the Bagno d'Ischia lying in a beautiful position on the borders of a little harbour. This was once a small lake formed in an old volcanic crater. Two springs constitute the Bagno d'Ischia, **Acqua della Fontana** and **Acqua del Fornello**, with temperatures varying from 131° to 138°. On the high ground behind the lake is the fine extinct crater of Montagnone, Westward stands Monte-Rotaro an extinct crater. Still further Monte Tabore. The road we are following skirts the base of all three in succession.

"Monte Tabore is composed of trachytic lava, resting on "a bed of clay in which are found marine shells of some species "still living in the Mediterranean. On the shore at the base of "this mountain is the **Acqua di Castiglione**, temperature 167°

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"at its source. The sand on the shore near it is so hot that "it raises the thermometer in a few minutes to 212° (?) and "there is a hot spring in the sea itself at a short distance from the beach so that one is enabled to take hot sea baths in the open sea. "The Stufe diCastiglione situated on the hills above "are vapour baths which issue from orifices in the lava at a "temperature of 122° in the lower, and 133° in the upper "stufa. The Stufe di Cacciato are of the same character as "those of Castiglione their temperature being 160°. The noise "of the water boiling beneath can be distinctly heard.

Casamicciola is the collective name for an assemblage of villas, bathing establishments and villages. At about the center is a hill called the Collina di Casamicciola on which stand the hotels. To the west of this hill upon the sea shore lies the village of Lacco Ameno. Eastward of the hill on the sea shore lies the Marina of Casamicciola. Between this hill and Mount Epomeo is a depression which Rossi claims to be part of the lip of the old submarine crater. At any rate it is just here, between Mount Epomeo and the hill of Casamicciola on a saddle which separates the valley running up from Lacco Ameno from the valley running up from Casamicciola that all old Casamicciola and Menella stand, that all earthquakes affecting Casamicciola have worked their greatest damage.

Casamicciola is noted for its hot springs, the most celebrated is the **Acqua di Gurgitello** (Temp. 162°) with extensive bathing establishments. Near here is the **Acqua di Cappone** (Temp. 98°) Near this is the Aqua del Occhio. Further up is the **Acqua di Tamburo** containing so much gas that it makes a noise resembling that of a drum. The temperature varies from 155°—210°. The Aqua Ferrata; Aqua aurifera Argentea the Aqua Spena Pollastro with a temperature varying from 167° to 180°. **Acqua Collata** 178°. The **Acqua Collata** varying from 178° to 190°. The **Acqua della Sciatica** with a temperature of 144°. In the valley running up from Lacco Ameno we find the **Acqua della Rita** ranging from 149° to 158° and the **Stufe** and springs of **Frassi and Monticel**, the former emitting vapour at 126° the latter at 203°.

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"Casamicciola is celebrated for its manufacture of bricks, tiles, and pottery in general, which are exported to Naples. The kilns extend along the whole length of the shore of the **Marina.**

In Lacco Ameno there are two hot springs, San Restituta (Temp. 135°) and the Regina Isabella (Temp. 106°) rising near each other. On the seashore the water exudes at 112° and near the little island of Capitillo it raises the thermometer to 171°.

Just beyond Locco Ameno are two spent volcanoes Monte Ricco and Monte Maricocco. The large promontory butting out here is formed by the lava of the latter.

On the road from Lacco to Forio we meet the **Stufe di** San Lorenzo, natural vapour baths (Temp. 135°). Nearer the shore in the same neighbourhood is the Aqua di San Montana (Temp. 131°). The ground around is sufficiently hot to raise the thermometer to 122°.

Forio is three miles from Casamicciola. A hot spring, **Acqua di Francisco Primo** rises here at a temperature of 113°.

One mile further near the shore rises the hot spring, **Acqua di Citara** of which Constantin James says "renomée depuis les temps les plus anciens comme possédant des vertus heroiques contre la stérilité, elle n'a du reste presque rien perdu aujourdhui de sa célebrité. De jeunes femmes privées du bonheur d'être mères viennent chaque année à Citara d'où la plupart emportent de douces esperances qui se justifient plus tard". Near here are hot wells and ancient vapour baths.

The road now mounts through Panza near an old extinct crater 2½ miles from Forio then more rapidly to Ciglio and still more rapidly through Serrara to Fontana which is just about the centre of the old crater. The lip of the crater is completely broken down on the south side while on the north it rises into the peak of Epomeo from which there is one of the most beautiful views imaginable. Here there is a little church and monastery half built in the rock dedicated to St Nicolas. Old Typhoeus however does not seem inclined to give up his patrimony without a struggle. The road now descends 2 miles to Moropano then 1 mile to Barano. Here the road

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bifurcates, one branch turning northward back to Casamicciola, the other one continuing along the bases of Monte di Vezza and Monte Campagnano, two extinct volcanoes. From here we go on to Ischia from which we started.

There are very few hot springs on the southern side of the island.

In ancient times long before our era the island was several times colonized but each time the inhabitants were driven away by volcanic outbursts. Since the beginning of our era several eruptions have been noticed, but not with sufficient detail to be of much use. The last eruption took place in 1302, when the Lava dell' Arso was formed near the town of Ischia.

EARTHQUAKES

I

February 2nd 1828. 10.15 a. m.

The shock of 1828 was one of the most violent of modern earthquakes though confined to a limited district. It was not felt on the adjacent coast or islands. Slight movements had been felt at 3. a. m. at Imola, Faenza and Forli (on the road between Bologna and Rimini, North of the Appenines) At 7 a. m. slight movements were felt at Foggio, San Severo, Barletta, Bari, also north of the Appenines, but much nearer the heel of the boot. The motion was from east to west.

In Ischia itself the earthquake consisted of an undulatory motion lasting four seconds. The sea was quite calm and remained so all day.

The disturbance was not preceded by any remarkable phenomena, except that in the morning Vesuvius sent forth smoke, flame, and stones. The springs did not exhibit any change that was specially noticeable.

Immediately before the shock, in the space of three seconds, three loud explosions were heard, which appeared to come from beneath upwards, or from the interior of Epomeo outwards; these explosions were very remarkable along the coasts of Casamicciola, Lacco, and Forio; but where the shock was most severe, that is that part of Casamicciola lying

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between Fango and Casamenella they were scarcely remarked.

In Casamicciola a part of the buildings fell together. Twenty eight persons were killed and many injured. In Serra-Fontana, Forio and Testaccio (south of Barano) no damage was done; but Lacco suffered remarkably.

The corpses were found in such positions as to indicate that persons had not even the time to be frightened so much so was this the case that Colvelli in his description was inclined to ascribe the whole thing to an electric discharge.

II

March 4th. 1881. 1 p. m.

The centre of disturbance seems to have been Casamicciola some damage was done where. There was a severe shock lasting some seconds which was followed six minutes after by a slighter one on March 4th 1881.

The following is the substance of a report signed by Guiscardi and dated the 21st August 1881.

At about five minutes past one in the afternoon of the fourth of March 1881 there was a shock felt in Casamicciola and a few moments later the ground was shaken again. Many houses fell; others were badly damaged; others less so: and others again remained uninjured. Many inhabitants were buried under the ruins where they perished. Shocks were also felt on the 6th the 7th the 15th and the 17th of March.

The intensity of the shock and the consequent havoc were not in proportion. The report ascribes this in most part as due to the bad construction of the houses—being mostly built of rubble. But even making all allowance for this, a great want of proportion between the shock and its effects is still noticeable. As can be seen from photographs, the walls are not wanting in thickness. Houses are never so badly built in Italy as to come down without very good cause.

Two areas can be distinguished in the extension of the seismical wave. The one is circumscribed by an elongated ellipse, the long axis of which runs from east to west and extends from Santa Barbara to Fango. In this area (which is just the depression between the hill of Casamicciola and Mount

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Epomeo) is included the greatest amount of damage.

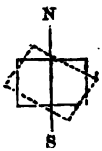
The next area is bounded by the sea, and a curve starting at Punta Porsone, passing along the base of Tabor and Rotaro, by the Casa Piaz, through the hamlets of Stennecchia and Spattara back to the shore again at Lacco Ameno. Within this area the shaking of the soil was still felt, but much less so than in the smaller ellipse.

Outside this second area effects of the earthquake are to be noticed at Santa Lucia del Vajola near Forio. In the south of island damage was done at Barano, Moropano and and Fontana. Fontana is due south from Casamicciola standing in the very center of the old crater. Fontana, Moropano and Barano are on a straight line.

Outside of the island, the earthquake was felt at Vivara, Bacoli, and as far as Ventotene in the Ponza group (Ventotene being about 25 miles due west from Ischia). Vivaro is the little island between Ischia and Procida. Bacoli is a little village on the coast near Baie. Here the shock was only noticed by one person, a lawyer named Cirillo.

It is to be noticed that the shocks outside the island were at the most so slight, that their very existence has been denied, and that they are not necessarily connected with the Ischian earthquake.

Several landslips occured. These were mostly on made ground such as roads and vineyards. In the ground only one crack about ⅛ of an inch wide, direction W. 30° E., was discovered. A square pilaster attached to a wall, at the height of the wall was found to have gyrated from S—N passing through W. some 5°. (See diagram)



Two other pilasters intended to ornament the wall to which they were attached were broken on a level with the top of the wall—the detached portion of the one fell down and the other gyrated like the one just-mentioned.

The church of Santa Maria della Pietà was reduced to ruins. In front of it was a little open space cut off from the street by an iron railing. Two columns of stone supported the iron railing and the iron gates. These pillars were square,

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9 feet high and ten feet wide. Each one was made of seven pieces and had on its top a cornice also of stone made of a single piece. The lower four fragments of the left hand pillar gyrated together as if on the tipped end of the right hand anterior corner so that the left hand corner has re-entered about 25 millimeters on a length of two feet, making an angle of about 2°. The fifth piece from the bottom remained stationary because it was fixed by the iron hinge of the gate. The sixth segment has gyrated like the lower ones, only it has come forward, the anterior edge protruding two centimeters, the posterior three centimeters.

The seventh fragment is also displaced but inversely to the one below—the front advancing four centimeters and the posterior right hand edge only two centimeters.

The lower four pieces of the right hand pillar have not moved. The others with the exception of the fifth were moved similarly to the lower four of the left hand pillar. The cornices of both pilasters were impelled outward from E. W. that on the left less than that of the right hand, the greatest advance being 1½ inches.

The parrochial church has its right side facing SE. Along the aisle are three chapels. The altar table of the the third is displaced so that its left side is six centimeters from its original position.

Three doorways in the whole place showed slight evidence of rotation.

At Lacco Ameno the shock was very perceptibly felt. The houses were only slightly damaged but the church very much so. In the third chapel on the right, the crucifix was found leaning against the painting behind it, and a chandelier on the altar of the second chapel fell on the table as if impelled in the same direction as the cross, that is from E. to W.

The Captain of the Carbonieri Bonu relates that on the fifth of March he went to Casamicciola, and saw the Church of the Purgdtorio all cracked (fissura). On a wall of this Church facing almost south in a niche there was a statue on a pedestal. This statue showed its right side, having turned

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to the West which was seen by the mark the turning had left upon the dusty pedestal.

The proprietor of the hotel Bellevue states that three small statues on the altar of a little church in the neighbourhood turned completely round, and that workmen in the neighbouring field were thrown on the ground.

A young country fellow showed the effect the earthquake had on him by repeating twice in an East West direction the motion which gymnasts call "spinta simultanea delle braccie in avanti" which he followed by a contrary motion. He accompanied the forward movement with a sound as from a base drum. Turning to look at Epomeo he found it covered with clouds.

Some ladies in Casa Pizzi felt the house rise while it was in part ruined.

A few days after the earthquake the microphone gave no results whatever.

It has been said that the mineral waters changed their level; but it is not known who made such observations. No importance can be attached to such reports. Moreover many of these springs are subject to normal variations.

I supplement this report by an extract from a notice by Palmieri.

A great subterranean noise as of something falling was heard, a cloud of dust arose, and the upper part of Casamicciola had crumbled. The Mayor of the place Dombre and several others who were in the streets at the time and only a short distance from the scene of disaster, are agreed that this was the beginning and the end of the affair and that it was accomplished in an instant. An apothecary who was afterwards saved almost by a miracle, relates that he heard a certain noise making him think of an earthquake and at the same moment he saw his shop crumbling about him. The inhabitants on the shore only

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Note. I have translated this report at length and insisted upon all the minute evidences of impulsion and rotation simply to show how very little of it there is any evidence of, in comparison with the other deplorable effects of the earthquake, for between Barbara and Fango hardly a house was left standing.

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felt a slight shock and they were far from suspecting the extent of the disaster. Three clocks although oscillating in diverse planes all stopped at the same time. About 120 persons perished under the ruins. By far the greater number of them were inside their houses. Very few were on the street, there not being time to get there. The corpse of a shoemaker was found in the very act of sewing a shoe he held between his knees. A woman was found dead in the act of darning a stocking. There does not seem to have been time enough even to get frightened.

There was no observed change in the mineral waters.

There was no motion perceptible in the microphone three or four days after the disaster.

There was a slight shock previous to and several shocks subsequent to the disaster.

The disaster was almost instantaneous and then all was over.

The area of the disaster was restricted. The line of demarcation was very evident. Just beyond this the damage was very slight and at some little distance further the earthquake was hardly felt at all.

Where the earthquake was most intense the damage was very great, indeed hardly a house remained standing

III

August 28th. 1883.

At the height of the bathing season when thousands of persons from all Italy and other parts of Europe were gathered together in Casamicciola, called thither by the great reputation its waters enjoy for the cure of nervous and rheumatic complaints; at an hour when the tired labourer was retiring to rest; when many of the inhabitants were gathered in the cafés smoking, chatting and drinking; when others had congregated in the theater; when many of the guests in the hotels were just beginning some festive entertainment, suddenly there was a crash, the ceilings and the roofs fell in, and 5000 human beings lost their lives.

It is rather difficult to know exactly when the earthquake took place. From the fact of a clock having been found stopped

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at 9.20 it is inferable there was a shock at that time; but the clock may not have been correct. The great shock took place at about 9.30 and was so severe that people in the theater were thrown in a heap and the petroleum lamps overturned. The summer theaters in Italy are generally very light structures without any roofs. This theater is one of the very few buildings which were not destroyed. One remarkable fact is that the houses of the marina (on the sea shore) suffered much less than others in their immediate neighbourhood, or even farther away from the seismic vertical. This however is not peculiar to this earthquake, but is common to all Ischian earthquakes.

"The first symptom was a distant sound like that of a "carriage, almost immediately accompanied by a tremor, "then a terrific explosion shading off into a number of reports. "Those in the mesoseismal area felt the blow and report "apparently simultaneously; the walls fell before any "attempt at an escape could be made"

There were several landslips. Two in particular on the northern slope of Epomeo over Lacco Ameno were rather extensive "The fissures were such as take place along the edges of all landslips. The presence of vapour for a short time after the earthquake was easily explained. The locality is part of the old fumarole area of Monte Cito, where alumn was manufactured centuries ago. The rock is much decomposed by the continued escape of acid vapour and only required the earthquake to shake it down. When the displacement took place a large surface of hot and moist tufa was exposed which no doubt for some time gave off a quantity of vapour."

No change of level in any locality, or in the fumaroles or mineral waters has been satisfactorily made out.

The mesoseismal area of the earthquake of 1883 corresponds almost exactly with the first isoseismal of 1881. In the mesoseismal area although all but four of five houses were destroyed the walls of many are standing. The roof and floors fell in. Objects are said have been projected considerable distances (a very unsatisfactory expression: one would like to know what object was projected? where it was projected from?

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how far it was projected? &c. &c.) The iron tie-bars put into the walls after 1881 are said to have been broken and bent like thin iron wire. The photographs give some evidence of bending but nothing like what the foregoing description would lead one to imagine.

The first isoseismal of 1883 corresponds almost exactly with the second isoseismal of 1881. In 1881 the houses were merely fissured and that not invariably. In 1883 many of the houses fell. The rest require rebuilding. This area is a very large one comparatively speaking, as it includes a part of Forio and Fontana.

The second isoseismal is altogether outside the effect of the earthquake of 1881 with the exception of the towns of Moropano and Barano which were also affected in 1881. In this second isoseismal of 1883 which includes all the rest of the island, with the exception of the eastern and southern coast, the houses are fissured sometimes severely.

"The third isoseismal does not seem to cut the land, its limits therefore are unknown. This area includes the town of Ischia and the southern coast where the effects of the earthquake have been very slight comparatively. The village of Fontana Servata standing on the very center of the old crater has been affected in a very peculiar way. Both in 1881 and in 1883 the shock was almost vertical, similar to what happened in the mesoseismal area, although it stands completely outside of it. In this last earthquake besides the fissures indicating a vertical shock, there are also fissures indicating a wave from North to South at a low angle of emergence.

At St Nicolà which stands on the top of Epomeo on the northern lip of the old crater between Casamiccola on the north and Serrata Fontana on the south, part of the altar has rocked from north to south.

Between St Nicola and Serrata Fontana a rock was ruptured and projected to the South.

Mr Petersen, the engineer of the zoological station at Naples, whilst dredging just about opposite Casamicciola found a number of pieces of pumice floating on the water, some of them as large as a man's head, having quite a fresh appearance.

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It is inferable that there was a submarine eruption somewhere near the island, and this might account for the sensation felt on board the steamer which was in harbour at the time of the earthquake, but it might be accounted for otherwise. It might have been shaken down from one of the sea cliffs. Besides if there had been a submarine eruption there would be something more to show than a few pieces of pumice.

Premonitory signs. It is extremely difficult to arrive at any reasonable approximation to the truth with regard to any of the phenomena attending the Ischian earthquake. When the subject of premonitory signs is taken up we find ourselves in a maze of confusion worse confounded; as assertions and contradictions succeed each other without end. Was there any seismic disturbance in southern Italy? Yes. Had it any intimate connection with the Ischian earthquake? Most decidedly, says one authority. Not in the least, says another.

Was there any change in the temperature of the mineral waters of Casamicciola? Yes there was. Now surely we have here a premonitory sign. No we have not, because these springs are known to vary 20° C. in their normal state. Were there any shocks before the 28th? For a full fortnight before the 28th there were almost daily slight shocks accompanied with subterranean rumblings. Then how is it that no mention was made of such phenomena? The owners of hotels were afraid to frighten away their guests. But then did not the guests feel and hear? No answer.

With so much conflicting evidence before us, let us collect what facts we can and reserve our inferences.

Professor Rossi of the central observatory in Rome has made two reports on the Ischian earthquake of 1883. These reports have not reached Japan where so much interest is taken in Seismology; which is a matter very much to be regretted. Some extracts from these reports however have reached us in the pages "Nature" for August 9th and 16th.

Rossi's Reports. Several days before the 25th and 28th of July the microcosmical instruments at Rocca di Papa and the connected microphones in Rome showed a great increase in subterranean activity. The earthquake which took place at

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Cosenza and Catanzaro on July 25th seemed to be the one predicted by these movements but their continuance and increasing force showed clearly the approach of a new dynamic effort.

The earthquake of Saturday July 28 was registered by the seismographs in Rome, Velletri and Cecano at 9.30 p. m. with slow waves from N.—S. and E.—W. The other instruments which register quick movements of the ground remained quiet.

This time as often before, the drying up of wells, subterranean thunder, and slight oscillations of the earth have preceded the catastrophe.

Not only were there for some days beforehand very distinct premonitory signs at Casamicciola of the impending catastrophy but also throughout the peninsula, forewarnings identical in character were numerous and wide spread.

On the island of Ischia there was an extraordinary increase in the temperature of the thermal waters and in the violence of the fumaroli at the spot called Monte Cito. These phenomena were noticed 8 days before the catastrophy occurred. On these important points the evidence which Prof. M. S. di Rossi obtained is abundant. There is less conclusive testimony concerning the shrinking and consequent scarcity of the drinking water in the wells. But he has absolutely certified, that commencing from a period a fortnight anterior to July 28th, many slight shocks of earthquake of almost daily occurence were felt and subterranean rumblings were heard.

While the above mentioned phenomena were occurring in Ischia without their being communicated to Rome or even for want of means, properly noted on the spot, the existence of unusual subterranean activity was simultaneously marked by the instruments in all the observatories of the mainland. That activity though varying in intensity in different places manifested a general and regularly progressive augmentation. Slight shocks of earthquake were felt at various points—On July 25th the Solfatara of Albano on the extinct Latin volcanoes on the southern side of the Roman Campagna sent forth sounds never before remarked. On the same day a widely extended earthquake reaching from Cosenza and Catan-

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zaro (towns respectively on the upper and lower part of the instep of the boot) occured in Calabria,

On Friday the 27th the hissing noises from the solfatara of Albano were so acute that the people did not dare to draw the sulphur water for those who needed it, and simultaneously the seismic instruments at Pesaro registered severe oscillations. At Vesuvius on the evening of Friday the 27th, shocks were felt with an augmentation of activity. There were shocks at Latera upon the Ciminian volcanoes and shocks at Perugia.

On the afternoon of the 28th renewed activity was manifested at Pesaro (on the Adriatic) and at Fermo in the same neighbourhood: and in short the observations during that afternoon throughout the peninsula, gave indications of a vast subterranean disturbance extending as far as all Umbria, the district of Viterbo and the Marches. All these places are North of Rome.

The direction of these extended movements was everywhere identical with those at Casamicciola, namely from North to South and from East to West.

At the same time also on the morning of the 28th the flow from the principal source of the sulphur streams near Tivoli showed a considerable diminution, while simultaneously an increased quantity of carbonic acid gas was given forth.

The regular observations at Bologna, at Pisanello, near Piacenza, and at Rome, showed that there was a distinct lowering in the levels of the wells before July 28th and a marked a rise after that date. These facts confer increased credibility on the imperfect evidence of there having been a difficiency of water in the wells at Casamicciola.

Moreover on the morning of Sunday the 29th, the usually very cold waters of the solfatara of Albano were in a boiling state.

The intimate connection between the phenomena on the peninsula and the catastrophy in Ischia which had a distinct dynamic and volcanic character, absolutely excludes the idea of a mere local sinking in the level.

A Rhenish Journal states that on Saturday night about the time when the Ischian earthquake occurred, a tremendous

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motion of the earth was distinctly felt at Wiesbaden.

On the morning of the 31st of July, also a shock was felt in Oporto, lasting two seconds, with direction east and west.

Two shocks are reported to have occurred on the same day at Gilroy, California.

A telegram from Athens states that a strong shock was felt at Piraeus on Saturday the fourth of August.

I hardly see any possible connection between earthquakes in Wiesbaden, California &c. and Ischia, when in the immediate neighbourhood of Ischia itself there is nothing of the kind. In all the earthquakes of Ischia it may be noticed, that the preliminary phenomena, always take place at a great distance generally on the north of the Appenines. It is difficult to understand why the cause or effect of all the phenomena so exactly and minutely enumerated by Prof. Rossi should be sought for in Ischia. Why should an old volcano near Rome be affected and the whole volcanic region in the neighbourhood of Ischia remain perfectly quiet? In the island itself what were the preliminary signs.?

The correspondent of the "Standard" in making the tour of the hospitals, found strong confirmation of the fact that there were signs of danger two or three days beforehand, which can not have escaped the observation of the inhabitants of the island but they were unfortunately, he says, suppressed in order to avoid giving alarm to the visitors and so spoiling an unusually prosperous season.

Now these preliminary symptoms are said to have consisted of great and sudden increase in the heat of the waters; in slight earthquakes and in subterranean rumblings, and that not only once but many times. Now I have yet to see an earthquake that you can suppress — and if there is one thing in this world that you do not get accustomed to, it is an earthquake. Out of the many thousand visitors was there not one who felt these earthquakes and heard the noises? If there had been, the inevitable did you feel it? did you hear it? would soon have made the occurrence a matter of public conversation. The earthquakes and their rumblings must have been very slight indeed. As to the increased temperature of the waters, we know that many of the

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springs on the island vary in their normal state and the bathers must have been accustomed to that, or there would have been a talk about it. For we must remember that only two years before there had been a great catastrophy and every one must have had his attention continually drawn to the subject by the newly plastered, or newly rebuilt houses.

Since the catastrophy of July 28th the following earthquakes have been noticed.

July 29	slight shock in the morning.		
Aug 1	slight shock	3.10	P. M.
" "	"	4.50	P. M.
" "	"	11.15	P. M.
Aug 2	"	2.30	P. M.
3	stronger & producing slight damage	1.15 or 2,15	
8	slight shock	10.40	A. M.
12	"	morning.	

Although the instruments on Mount Vesuvius did not register the shock of the 28th of July they have registered the subsequent one. Some malicious people may be inclined to think that the instruments were not in proper working order at the time of the great catastrophy.

To account for the Ischian earthquake several theories are put forward—one has been suggested to me by Prof Milne he says "Why can not the Ischian earthquake be attributed to "the formation of a fissure produced during the process of "elevation: the earth oscillations of this portion of the world "have formed a subject for every text-book on geology and in "Ischia itself there are raised beaches indicative of a recent "upward movement". Mr. Johnston Lavis in a letter to "Nature says "In various points that I have examined the "coast of the island there was no apparent change of level nor "did any success attend endeavours to discover any signs of "depression of the surface".

Then there is the volcanic theory which is best stated by Mr. Jonhston Lavis in his own words. A careful examination of observed azimuths and angles of emergence all point to a plate shaped focus whose strike extends in a line from

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Fontana passing just west of Menella to near the beach at Lacco. The plane of this fissure is probably roughly perpendicular to the surface but may slightly dip toward the east as the isoseismals are slightly nearer on the eastern side of the seismic vertical which as a necessity is not represented by a point but a line on the surface—the rupturing of this plate-like fissure was apparently greatest at a point nearly midway between its extremities.

That Vesuvius did not or only did to a slight extent sympathise with the seismic movement in the island of Ischia is no proof against the volcanic origin of the earthquake. Admitting the hypothesis of a seismic wave traversing a large tract of volcanic matter underlying southern Europe, such a wave might produce but very slight variation at volcanic vents yet be sufficient to dertermine the extension by rupture of a fissure where the resistance of the rock and the tension of the volcanic matter near the point of extension were nearly equal.

In a paper lately read before the Geological Society of London I endeavoured to prove that the explosive violence of lava is due to the assimilation or solution of water taken up from the water bearing strata it traverses in its passage from the main source toward the surface. Under such conditions we may have very violent phenomena produced locally without any sympathy in neighbouring volcanic vents; which at the same time explains I believe one volcano bursting out in a violent paroxysmal eruption whilst a near companion is in no way affected. Why therefore should an abortive paroxysm disturb a neighbouring active vent as in the present example.

We must expect other shocks more violent in character and that as one follows the other the interval of tranquility will be less until the final eruption bursts forth. The seismic vertical at Casamanello stands in the same relative position to Epomeo that do many of the parasticis cones.

Professor Rossi of Rome who is also a strong pastisan of the volcanic origin of the Ischian earthquake insists upon the fact that Casamicciola or at least that part of it which suffers the most is on the point of intersection of a longitudinal fracture coming from Mount Epomeo and a transverse fracture

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representing the brink of the old submarine crater. That it was just astraddle of the lip of this old submarine crater that the most damaged portion of Casamicciola stood. That the longitudinal fracture will account for the damage in Lacco Ameno and that this longitudinal fracture is just the principal one of the Ischian volcanic system as it lies in the axis of the ellipse of the two craters, that is of Epomeo itself and of its predecessor, coinciding with the line of the falling away of the Crater towards the south.

Professor Rossi also lays great stress upon the premonitory signs which he has noted. I doubt however very much whether all the signs he has noted have produced as much impression upon others as upon himself.

The theory of Luigi Palmieri. Earthquakes which are generated by subterranean impulses have certain common characteristics which are as follows:—

I. All Earthquakes of a certain intensity which have been the cause of ruin and devastation have been felt over an *extended region* and the extent of the region subjected to the shock has always been more or less proportional to the vehemence manifested within the central area.

II. There has never been a case recorded where an earthquake of sufficient intensity to overthrow houses has accomplished its work in a single shock. Violent shocks succeed each other at first with short intervals, then with longer intervals and lessening intensity. The first shocks at the most only partially destroy the houses which afterwards fall with other earthquakes. Hence the popular belief that an earthquake must have its echo.

III. During a seismical period between one shock and another the earth apparently is still subjected to a tremulous movement perfectly appreciable with proper instruments, and this movement is noticable for many days.

IV, Shocks generally last several seconds and almost invariably the length of the shock has a certain affinity with its intensity. We may always be sure that weak shocks of long duration are never local earthquakes. On the other hand a shock lasting but a few seconds is never one of remarkable intensity.

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V. The sea suffers extraordinary agitation, its waves often rolling several kilometers into the land.

VI. The water of springs generally gives warning of the terrible phenomena either by becoming low or else becoming turbid. Often indeed there is an unusual agitation among domestic animals.

These being without doubt the characteristics of the greater number of earthquakes there are nevertheless others which present a very different series of phenomena. A subterranean falling in of the ground whether accompanied with depression of the soil or not may produce the effect of ruined houses. Again we may have the same effect produced by an elevation of the soil relatively long without any shock at all.

In 1861 a part of the town of **Torre del Greco** was raised a meter and a half above sea level. All the houses one after-another fell without there having been felt the least commotion of the ground or the least shock. The ground was undergoing a slow elevation during which it cracked giving forth frequent signs of heat and various gases. All this damage was accomplished in less than 36 hours and while the whole length of the street called Copotone lay in ruins, the rest of the town remained intact.

In the beginning of May 1877 in Marano of Calabria, many, in fact most of the houses fell in with a certain leisure one after the other: no one having felt any shock and the soil was observed to be cracked and evidently depressed. Here also the damage done was very much circumscribed.

Gaetano Torre, a civil engineer, in a pamphlet published in 1871 mentions the fact that he was witness of depressions in the valley of the Velino in Abrazzi, in a town where numerous springs rich in carbonic acid eat into the calcareous rocks below and deposit large quantities of carbonate of lime on the ground.

These movements of the soil by which houses may be laid low through subterranean caving whether slow or rapid have not the characteristics of those previously described. They are generally confined to some difinite town and if they

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last any time the houses fall without any appreciable commotion of the ground: they seem to fall of themselves. But if they happen suddenly they do the work at once and repititions of the shock if there be any, are very slight and of no importance. The surface of the ground may have been moved and yet there be no depression if a subterranean arch exists as has been noted by **Fuchs**. Seismic apparatus in this kind of earthquake will always remain quiet even if placed at a short distance from the scene of disaster nor can they ever give those useful preventive indications which are the principal object of Seismology.

Volger believes that all earthquakes are caused by subterranean falling in or by fractures and fissures. If this were true seismology would be impossible. In fact this is probably rather the exception than the rule when we think that the earthquake of Lisbon caused all Europe to tremble; that the earthquake of Calabria caused all Sicily to tremble terribly shaking up the sea: that the shocks followed each other with variable intensity lasting sometimes 50 and even 60 seconds; that large gaps in the earth were opened and shut; that the heaviest objects were elevated in the air, it would be impossible to ascribe all this to subterranean falling in or a fissure. Real earthquakes, those to which seismology devotes itself are the effects of the same endogenous activity which also produces Volcanoes. Fachs believes that such earthquakes should take place only in the neighbourhood of volcanoes, but then we should be obliged to consider as non-volcanic some of the greater and most disastrous of earthquakes which have shaken the soil of Europe to say nothing of those in Asia and America.

Apart from the probable caverns caused by the thermal waters rich in carbonic acid coroding the trachytic rock there is at a still lower level a bed of clay the extent of which is unknown. All the bricks, kitchen utensils and tiles manufactured either in Naples or on the island itself are made of this clay which is extracted from deep wells and subterranean galleries. The engineer Alexander Giordano who in 1834 was sent by the Government to examine these excavations

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reported that they put the buildings of Cassamicciola in the greatest danger. He proposed the discontinuation of many workings, and that none in future should be opened at a less distance than 300 meters from the buildings.

If Casamicciola had been merely shaken by an earthquake these immense caverns so long as there was no falling in should tend to diminish the shock according to a law of of Pliny which has ever been held true by seismologists. In the earthquake of Melfi, Barile although nearer than Rapalla to the seismic center suffered less, just because it was built above a lot of grottoes.

In order to reconcile the great damage done with the restricted sphere of action and the suddenness of the effect there are but two possible hypotheses. A tremendous subterranean impulse similar to a mine exploding at a very slight depth or else a great caving in of the subterranean soil. I do not repudiate the first, but I think the second much more reasonable. I can understand the first causing a slight earthquake but not being the efficient cause of such a disaster.

When did it ever happen that a town was overthrown by an earthquake without occasioning damage at least 60 miles round? When did it ever happen that an earthquake caused one half a town to be overthrown while the other half remained intact.

That the source of the shock at Ischia must have lain comparatively near the surface may be confidently inferred. Had it been more than a few hundred feet deep the waves of such a shock would assuredly have been propagated to a considerable distance all round.

The sudden snap of large masses of rock under great strain may be the origin of the frequent earthquakes of mountain chains such as those so constantly experienced in the Alps. In volcanic regions earthquakes usually preceding and accompany volcanic eruptions have been plausibly attri-

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1. It must be remembered that even in this last earthquake the houses of the Marinas have sustained comparatively little damage. To which may be added the opinions of a writer in "Nature" Aug. 9th 1883.

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buted to the explosion of elastic vapours. Ischia lies in a volcanic district and is itself of volcanic origin but its earthquakes do not seem to be part of the active volcanic phenomena of the district. So far as information is yet available regarding the recent catastrophy there appear to have been no accompaying volcanic manifestations though there were many active vents where they might have been expected to show themselves.

Note. In confirmation of which H. J. Johnston-Lavis writes to "Nature" Sept 6th 1883.

I have visited with care all sites of supposed fissures but after some days of want of shelter and sleep, an abominable starvation diet of bad bread and rotten cheese, combined with continual climbing from daybreak to sunset in an extraordinarily hot Neapolitan summer in the hope of finding some evidence of volcanic action did not meet with the slightest success. I was accompanied in these excursions by my friend Prof. P. Franco of Naples who shared my disappointment and disgust. Holding as I do the volcanic nature of the earthquake the appearance of any such phenomena would have been greedily accepted.

To again quote from the article in "Nature" Aug. 9th.

So far as materials exist for forming a judgment on the subject of the recent earthquake at Ischia, it appears to have been caused by the sudden collapse of some subterranean cavern situated not far below the surface in the Casamicciola district. Such caverns no doubt frequently exist underneath volcanic rents from which large masses of material have been emitted. It is well known to geologists that one of the final phases in the history of a volcano is the subsidence of the cone. This downward movement probably continues during a long period of time. It may be on the whole gradual and imperceptible but if from time to time the roof of the huge vessicles whence lava and steam have escaped should give way, though there may be no perceptible change of level at the surface, such shocks will be generated as to convulse the area with earthquakes. We may infer that the Ischian earthquakes are the result of the former extravasation of volcanic materials and

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the "consequent vessicular conditions of the earth's crust at "the locality, but we must await the careful collection of "evidence before any positive conclusion on the subject can be "embraced"

RESUMÉ.

What then do we really know about the Ischian earthquakes? Whatever is admitted by all or denied by none may be accepted as true.

All Ischian earthquakes of which any special record has been made resemble each other, in fact are a counter part of one another, differing only in intensity, having a special type of which the following are the common and constant characteristics.

1° If there are any premonitory signs one never hears of them until after the earthquake has taken place. There are always prophets after an event.

2° Great suddenness; there is but one serious shock and all is over. Succeeding earthquakes are of very little importance.

3° Extreme localization. There is not a gradually diminishing intensity of the seismic wave as it recedes from the seismic-center, but the area of damage is clearly marked.

4° The cause of the earthquake whatever it may be, whether it be fissure or the formation of a volcanic rent or a subterranean falling in, or explosion, or what not, is comparatively near the surface.

5° There are no evident volcanic phenomena accompanying the earthquake.

6° If the seismic wave is felt outside of the island at all it is felt very slightly.

7° There is no disturbance of the sea.

8° Three days after the earthquake of 1881 there was not the least vibration of the soil discernible even with a microphone. Strange to say no notice one way or the other has reached me with regard to the earthquake of 1883.

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CONCLUSIONS.

I. That it is very much to be regretted that after the disaster of 1881 no efficient measures were taken to investigate the physical phenomena of the island of Ischia.

II. That it is very difficult to arrive at any positive conclusion from reading the different reports. On doing so, one has an intimate feeling that every one goes there with a preconceived theory and only hunts out facts to corroborate it.

III. The fact of the earthquake not having been sensibly felt in Naples or on the adjoining shore should not influence our judgment much either way, for in 1857 Capri scarcely felt the shock which was very severe in the promontory of Sorrento. Now the promontory and the island belong to the same geological formation and are very near each other.

On the other hand the motion noticed by Prof Rossi in his instruments at Rome, and the various phenomena he mentions in connection with the Ischian earthquake, as happening at that time near Rome, are not by any means necessarily connected with the Ischian earthquake.

Although in all Ischian earthquakes some commotion on the continent has been noticed, this commotion has invariably taken place at a very considerable distance, while in the immediate neighbourhood no motion was perceptible. It is very problematical whether these distant motions are anything but a coincidence.

IV. When one thinks of the enormous amount of lava which has been ejected from the many cones on the island one can understand that there may be enormous cavities below the soil.

When we consider the corroding influence of carbonic acid and water: and the great number of hot springs and the quantity of water they are continually pouring forth and have been pouring forth since time immemorial, that cavities may exist becomes still more evident.

If besides this, we remember that sufficient clay is being continually taken out of the soil to furnish bricks, tiles and cooking utensils not only for the island itself but for all the

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neighbouring mainland; that this clay is not on the surface but is all taken from excavations and galleries, mined as it were; that this process is by no means a new one but has been going on for generations; we see then causes tending still further to honeycomb the soil. The soil therefore being, cavernous, a sudden collapse is not only possible but probable, and we can understand that it might produce remarkable effects.

V. The great suddenness and localization of the Ischian earthquake, together with the absence of any volcanic phenomena, should induce us to seek some other cause for the earthquake than a volcanic one; and as we have a set of conditions in the nature of the ground itself amply sufficient to account for most of the phenomena, we are justified, in the absence of further evidence in considering this as an efficient cause. Whether the accidental cause was a fissure, a seismic wave, or an explosion or what not, is a consideration which only a lengthened and methodical observation in the future will enable us to find out.

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CATALOGUE OF EARTHQUAKES FELT IN TOKIO BETWEEN JULY 1883 AND MAY 1884.

THE OBSERVATIONS WERE MADE AT THE METEOROLOGICAL OBSERVATORY (CHIRI KIOKU) BY PALMIERI'S SEISMOGRAPH.

(For the first portion of this Catalogue see Transactions of Seismological Society of Japan. Vol. II pages 3. and 39 and Vol. VI page 36.

1883	Month	Day	Time			Force	Direction	Duration
			about					
498	VII	27	14	25	00	—	—	—
499	VIII	17	2	38	41	—	—	24s
500	X	3	15	8	11	7°10′ 4°40′ 6° 0′ 4° 0′	N or S NW or SE W or E SW or NE	33s
501	XI	26	3	47	27	—	—	—
502	,,	,,	16	29	00	3°50′ 2°50′ 3°10′	N or S NW or SE W or E	49s
503	,,	29	16	29	21	2°20′ 1°20′ 1°10′	N or S NW or SE W or E	25s
504	XII	4	2	38	29	0°50′ 1°30′ 1°30′	NW or SE W or E SW or NE	—
505	,,	20	4	22	28	—	—	—
506	,,	21	18	54	0	1°40′ 1°30′	NW or SE W or E	—
507	,,	25	4	55	30	2° 0′ 1° 0′ 1° 0′ 1° 0′	N or S NW or SE W or E SW or NE	—
						1884		
508	I	2	1	19	59	11°10′ 15°30′ 28° 0′ 16°25′	N or S NW or SE W or E SW or NE	about 2m
509	,,	4	2	16	53	—	—	—

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1888	Month	Day	Time	Force	Direction	Duration
510	,,	10	9 0 51	4°05′ 4°10′ 4°40′ 4°50′	N or S NW or SE W or E SW or NE	—
511	,,	19	12 53 34	4°00′ 2°00′ 5°10′ 5°30′	N or S NW or SE W or E SW or NE	43ˢ
512	,,	20	7 51 41	—	—	—
513	II	21	18 16 04	1°10′ 0°20′ 2°00′ 0°20′	N or S NW or SE W or E SW or NE	—
514	,,	22	about 14 40 00	2°40′ 1°30′	W or E SW or NE	—
515	III	1	about 9 05 00	—	—	—
516	,,	18	about 16 50 00	—	—	—
517	,,	,,	about 19 10 00	—	—	—
518	,,	14	8 58 25	—	—	—
519	,,	15	8 24 33	—	—	20ˢ
520	,,	17	9 03 21	1°50′	N or S	—
521	,,	31	8 22 00	0°40′ 1°40′ 1°20′	NW or SE W or N SW or NE	—
522	IV	4	9 34 03	0°10′	W or E	—
523	,,	5	12 23 00	5°00′ 3°00′ 3°10′ 2°10′	N or S NW or SE W or E SW or NE	1ᵐ00ˢ
524	V	6	5 37 37	3°20′ 2°40′ 3°10′ 4°00′	N or S NW or SE W or E SW or NE	1ᵐ04ˢ
525	,,	,,	9 00 21	3°00′ 1°30′ 1°30′ 2°50′	N or S NW or SE W or E SW or NE	0ᵐ30ˢ
526	,,	11	9 45 27	9°00′ 8°50′ 6°30′ 4°10′	N or S NW or SE W or E SW or NE	about 1ᵐ50ˢ
527	,,	11	20 23 27	0°10′ 2°10′ 1°10′ 2°20′	N or S NW or SE W or E SW or NE	—

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1888	Month	Day	Time	Force	Direction	Duration
528	V	19	0 28 48	1°10′ 3°00′ 1°50′ 0°10′	N or S NW or SE W or E SW or NE	about 0m10s
529	,,	19	11 34 45	0°10′ 0°40′ 0°40′ 0°50′	N or E NW or SE W or E SW or NE	about 0m07s
530	,,	27	11 10 50	2°20′	SW or NE	—
531	,,	28	1 54 42	—	—	—
532	,,	29	11 29 38	—	—	—
533	,,	31	0 59 48	1°00′ 1°00′	NW or SE W or E	—

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SECRETARIES' REPORT.

June 19th 1884.

During the past year although the society has lost the immediate assistance of several of its members a fair amount of work has been accomplished. Vol. VI. of the Society's Transactions has been published and issued to the members. A large number of copies have also been circulated amongst leading societies in different parts of the world. These gifts have been responded to by numerous exchanges, a list of which will be shortly published. An epitome of Volume I has been printed in Japanese, and copies of the same have been distributed amongst the Japanese members of the Society. Other copies have been given to those Foreign members of the Society who expressed a wish to receive the same.

Considerable work has been accomplished by a special committee appointed to report on a system of Earthquake Observations.

The conclusion arrived at is, that the most important observations are those of "Time," and several special clocks intended to record the time at which an earthquake occurs have been constructed and experimented upon. It is the intention of the committee to recommend on behalf of the Society one of these clocks to the Imperial Government, as a type of instrument to be used in several of the Telegraph Stations.

During the past year seven general meetings have been held at which a number of valuable papers have been read and discussed. Although the opportunities for the actual observation of Earthquakes in Japan have, as compared with previous years, been unusually few, Seismology has received considerable attention in consequence of the disasters which have occurred in other parts of the world.

Dr. Wagener has read before the society a long and valuable paper on the Krakatoa disturbance while Dr. F. Du Bois has read another valuable paper on the Ischian Catastrophe.

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A paper of especial interest to those resident in this country is a detailed account of 387 Earthquakes recently felt in North Japan, by Prof. John Milne. On account of the length of this communication and the series of maps with which it is accompanied, which the Society has undertaken to publish, the paper will not appear for some months.

In conclusion we may add that in consequence of the disturbances which have shaken Europe and other countries, several communications have been received, relating to the Society's publications and the instruments which are employed in this country.

The balance sheet from the Treasurers' is appended.

JOHN MILNE.
D. KIKUCHI.

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ON 337 EARTHQUAKES OBSERVED DURING TWO YEARS IN NORTH JAPAN.

October 1881—October 1883.

by

JOHN MILNE.

[Read April 21st 1884.]

CONTENTS.

1. *Introduction.* Explanation of methods of observation. Instruments employed &c.

2. *Catalogue of Earthquakes.* Facts which have been recorded. Here and there a few deductions based on data relating to special earthquakes are given, &c.

3. *General results.* Origins of Earthquakes. Earthquakes in relation to the Seasons, Tides &c. Nature of earthquake motion &c.

4. *Maps and diagrams.*

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I. INTRODUCTION.

The following paper is an account of 387 earthquakes observed in North Japan between October 1881 and October 1883. The area of observation lies between 35° and 44° North Latitude. It is shown in any one of the maps illustrating areas which have been shaken.

The shaded portions of these maps indicate mountainous districts, embracing hills from 500 to 1000 feet in height, and peaks, which in the central parts of the country attain heights of from 6,000 to 10,000 feet.

The coloured portions of these maps indicate areas which have been shaken by different earthquakes. Some disturbances have been so small that they were only observed at one town. Other have been sufficiently great to be felt almost over the whole area shewn in the map.

The maps are arranged in groups. Those maps which represent Earthquakes which have shaken neighbouring or approximately the same districts being placed near to each other.

The extent of country over which an earthquake was felt was determined as follows. First I distributed bundles of post cards to the government offices in all the important towns within a distance of 100 miles of Tokio, with a request that every week one of the cards should be posted with a note of any earthquakes which might have occurred. In consequence of the kindness of the officials at these offices, whom I now take the opportunity to thank, I soon discovered that almost every disturbance came to Tokio from the North and passed that city to the South and West until it reached the Hakone Mountains where it was suddenly stopped, as was indicated by the fact that those who resided in towns beyond these mountains had not noticed an earthquake to have occurred.

This fact having been established the barricade of post cards was extended towards the North, until finally I had

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observers at all the places indicated in the following list.

On the map with the exception of Yokohama and Tokio each station is simply indicated by its number.

LIST OF STATIONS.

Number.	Place.	Number.	Place.
T	Tokio	23	Numatsu
Y	Yokohama	24	Shidzuoka
1	Hojo	25	Tateyama
2	Otake	26	Taira
3	Mohara	27	Nakamura
4	Sakura	28	Wakamatsu
5	Choshi	29	Nihonmatsu
6	Narita	30	Yonezawa
7	Sakai	31	Yamagata
8	Asaw	32	Sendai
9	Mito	33	Kesen
10	Shimoda	34	Ichinoseki
11	Utsunomiya	35	Morioka
12	Ashikaga	36	Miyako
13	Takasaki	37	Komoro
14	Numata	38	Ida
15	Hachioji	39	Kamaishi
16	Fuchiu	40	Funai
17	Kofu	41	Hakodate
18	Nakanomura	42	Sapporo
19	Shimoda	43	Akishi
20	Yokosuka	44	Nemuro
21	Odawara	45	Niigata
22	Hakone		

Correspondence was occasionally received from many other places.

When an earthquake was recorded at only one of the stations it was assumed that the disturbance was quite local. Generally speaking the records of a given earthquake came from a group of places lying near each other. It has often

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happened that a number of places have recorded an earthquake, whilst from two or three places in the midst of the same area no records have been received. In such a case it is assumed that these omissions have been accidental, the earthquake not having been felt; perhaps on account of its feebleness, perhaps because it occurred when the observer was out of doors, or in the middle of the night when he was asleep.

As a rule the areas on which earthquakes have been felt are along the eastern side of the country, the western extension of the disturbances being limited by heavy mountain ranges.

The most remarkable observations are those from two or more *groups* of places distant from each other, each group of places reporting an earthquake as having occurred at the same time.

These time observations are in the majority of cases only approximate, and if two towns report an earthquake on the same day and at a time not differing by more than 30 minutes, expecially when the observation is made at night, I have assumed that the records refer to the same shock.

The only places at which good time observations have been made are the following—Tokio, Yokohama, Chiba, Kumagai and Kamaishi.

At the first two of these places the records were made by good clocks from which the time was taken automatically. These observations were often checked by several observers. The clocks at all the places were generally compared several times per week by a telegraphic signal which is sent throughout the country every day at 12 o'clock. For the use of this signal my thanks are due to Mr. T. Ishie the Director of the Imperial Telegraphs of this country.

At Hakodate and Sapôro the time was obtained by comparison with chronometers at the observatories at these places. For these observations I have to thank Mr. N. Fukushi, Director of the Survey Department in Saporo, and his assistants in Hakodate.

All these times have been reduced to Tokio mean time.

From the area over which a shock was felt, the intensity of it at different points, the manner in which previous and

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subsequent disturbances have occurred in the same area, the time at which the shock was recorded at different stations, and from these and the directions indicated by instruments, origins have been determined for nearly all the earthquakes to which reference is made.

It is needless to remark that these origins are only approximate, and although for convenience these origins are referred to as points, it is probable that many shocks may have originated from fissures of considerable extent.

In all cases details of calculation are omitted.

When obtaining an origin by time observations the method employed has usually been either that of Hyperbolas or that of Circles. (See Trans. Seis. Soc. Vol. II p. 69 and Vol. III, p. 132).

The instruments used were of many types, including the majority of instruments referred to in the Transactions of the Seismological Society.

The simplest are series of columns which are overthrown by severe shocks. Another instrument which I have largely used is a ***dead beat*** pendulum with a multiplying index writing its record on a stationary plate of smoked glass. Instruments of this type I have had in Tokio, Yokohama, Chiba, Kisaradzu, Kamaishi and Saporo. I have placed similar instruments in other parts of Japan but these records are not referred to in this paper. A large number of these static records like Figs. 2, 3, 4 &c. have been reproduced by tracings made from photographs.

Another set of records are those drawn by various forms of bracket seismographs, conical pendulums and rolling sphere seismographs. These records were made on smoked paper or glass, the record receiving surface being either continuously in motion or only set in motion at the time of the earthquake.

These instrument are all designed to give with but slight error a diagram of the actual movement of the earth, with regard to its amplitude, its period of vibration, and its direction.

Inasmuch as it will be observed that different instruments give different results for the same earthquake, in order

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that the reader may not regard such diagrams as conflicting, the following results, which have been obtained from the earthquakes here referred to and which have been confirmed by many observations made subsequently, may be enumerated.

1. An ordinary earthquake, although having a general direction of propagation, has at a given point many directions of vibration. If there is a decided shock in a disturbance this particular movement may be indicated in the same manner at adjacent stations.

2. The amplitude of motion as observed at two adjacent stations even if only a few hundred feet apart may be extremely different.

3. The period of motion may vary like the amplitude, the instruments being in all cases as similar as it is possible to construct them.

At present I am carrying on observations by means of three similar instruments placed at the corners of a triangle the sides of which are about 800 feet in length. When these instruments are side by side they practically give *similar* diagrams. At their present positions they always give *different* diagrams. If these instruments were in the hands of distinct observers each of these observers would give a totally different account of the same earthquake. Judging from the quick period and large amplitude of motion always observed at one particular corner of my triangle, I can say with confidence that at this corner there might be sufficient motion to shatter a building, whilst at the other corners, similar buildings would not be damaged.

Other results which have been obtained will be enumerated subsequently.

A description of many of the instruments by which these results have been obtained will be found in the pages of the Transactions of the Seismological Society. A description of the principal instruments which I have used together with a comparison of their relative merits will be found in Vol. IV. of the above mentioned Transactions p. 85. &c.

In Tokio the places of observation were as follows.

1. *Yamato Yashiki* (Imperial Meteorological Observatory.)

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At this place, which is situated at the foot of a steep slope rising from the Tokio plain, there was for many years one of Palmieris' instruments. About November 5th 1882 this observatory was moved to a point about 1 mile distant, in the center of Tokio near the grounds of the castle.

In the Yamato Yashiki records quoted in this paper the intensity in different directions is indicated by degrees and minutes. Thus WNW 30′ means that mercury contained in the WNW tube was caused to oscillate until an index connected with a float on the mercury had turned through 30 minutes of arc.

2. *Yama Guchi Yashiki.* Until 1882 this was my private residence. Here a variety of instruments were in use. The situation is about half way up the slope at the foot of which the Yamato Yashiki observatory was situated.

It was a this place that most of the diagrams given in this paper were obtained. One common characteristic of them, is their smallness as compared with others taken in different localities. From more recent experiments I now know that had I moved my observatory about 100 yds distant down to the flat ground, the amplitude of motion indicated in the above diagrams would at least have been doubled. A series of diagrams obtained with the same instruments installed on the flat ground, I hope to publish in a subsequent paper.

3. *Kobu Dai Gakko.* (Imperial College of Engineering) This place is about a quarter of a mile distant from the two former places. It is situated on tolerably level ground raised almost 30 feet above the flat ground on which the greater portion of the city is built.

4. *Dai Gaku.* (University).

This is situated on the flat plain of Tokio, about two miles distant from the former places.

It was here that Prof. Ewing's instruments were observed. This is a good locality for obtaining records. At this place large amplitudes of motion have been noted whilst at other parts of Tokio the same earthquake has been passed by unnoticed.

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In Yokohama I was greatly assisted in my observations by Messs. Talbot, Bisset, Pryer and Owston. The former of these gentleman built a special observatory in which a variety of instruments gave a series of valuable records. Nearly all the observations in Yokohama were made on a plateau 100 feet above sea level bounded by steep bluffs.

In interpreting many of the records which have been obtained, it must be pointed out that much assistance has been obtained from records which had been obtained previously and also subsequently to the years which are particularly referred to in this paper.

Examples of the earliest observations which were made commencing in 1876 have already been laid before this society.

In a Memoir of the Science Department of the Tôkiô Daigaku published in 1883 on Earthquake Measurements the author, Prof. J. A. Ewing, remarks that so far as he "is aware no continuous record of earthquake motion had been previously obtained"—that is prior to his own observations in November 1880.

The first continuous records which I obtained, which were published in the Transaction of the Seismological Society, were made at the end of 1879. These however only represented a small portion of the earthquake not lasting over more than six seconds. They were however sufficient to enable me to state, that earthquake motion was irregular, that its amplitude was only a few millimeters, and that there were only 2 or 3 vibrations per second. Prof. Ewing's records which succeeded these were certainly more complete, inasmuch as the earth's motion was magnified and the period over which a record was drawn was considerably increased.

About this time continuous records were also obtained by Father Faura of Manila.

The horizontal lever seismographs which have played such an important part in Seismology were first used by Prof. W. S. Chaplin. A similar instrument was subsequently but independently constructed by Mr. T. Gray. Neither of these gentlemen so far as I am aware obtained any records. Still later, in Nov. 1880, the instrument was again reproduced

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but in an improved form. The friction of its parts had been reduced, a multiplying index had been added and the principle of its action enunciated. It was with this instrument, the successful working of which is due to Prof. Ewing, that good results were first obtained.

For great assistance in working up the numerous records which I have received, my best thanks are due to Messrs. Kuwabara and Matoba of the Kobudaigakko, without whose help I should have experienced great difficulty.

II. CATALOGUE OF EARTHQUAKES.

In the following catalogue the various earthquakes which have been recorded succeed each other chronologically, and are numbered consecutively.

—— 1 ——

1881. Oct. 2.

Hakodate 9.30

—— 2 ——

Oct. 19.

At 3. 11.30 A. M. feeble. N. W.

—— 3 ——

Oct. 19.

At Hakodate 9.28 P. M.

—— 4 ——

Oct. 21.

At 8. 2 A. M. feeble. S. W.

—— 5 ——

Oct. 22.

At Saporo 6.20 A. M.

—— 6 ——

Oct. 24.

At Hakodate 2.57 P. M.

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—— 7. Map 1. ——

1881 October 25th 9.24.15 P. M.

This shock was felt all over the eastern part of north Japan, being strong in the north at Hakodate and Saporo and comparatively weak in the south near Tokio.

TOKIO. *Yama Guchi Yashiki.* The shock was short and gentle. A lamp swung NW. SE. A pendulum seismograph (Fig. 2) gave a clear record of motion, first N 5° E to S 5° W. and subsequently E and W. The maximum amplitude of the first displacement was 1.9^{mm} and of the second 1.3^{mm}.

A pair of conical pendulums (Fig. 1) indicated a motion extending over at least 45 seconds. The components were N 17° E and E 23° S. The former of these was the larger. The period of the vibrations at the commencement of the disturbance was .46 sec. After 20 seconds of motion the period became almost 2.5 seconds.

A bracket ring seismograph (Fig. 5) indicated a slight movement E 23 S. The period was about .3 sec. The portion of the instrument recording motion N 23 E was not in working order.

A double bracket seismograph (Fig. 6) indicated a slight motion commencing with a period of about .3 sec and dying out with slow waves. There was no vertical motion.

As the record given by these two last mentioned instruments was so extremely small, only 6 seconds of the disturbance has been shown in the Figures.

The time at which the disturbance commenced was 9.24.22 P. M.

Kobu-Dai-Gakko. Out of a set of columns, only one small inverted cone fell. It stood on a platform with a spherical base.

Yamato Yashiki Observatory. Time 9.24.15. Directions NNE and NNW 10′, WNW 30′. Duration $1^{m}.30^{s}$.

YOKOHAMA. Time (Talbot) 9.24.45 P. M.
(Owsten) 9.24.42
The mean of the above is 9.24.43

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A pendulum seismograph (Fig 4) indicated the principal motion N 20 E with an amplitude of 9^{mm}. There were also movements transverse to this.

The shock is described as having been sudden. It was followed by gentle tremors.

CHIBA. Pendulum seismograph. (Fig. 3). Direction. N 62 E with smaller transverse motions slightly E of N and W of South. The former had a maximum amplitude of $.8^{mm}$ and the latter $.1^{mm}$. It is doubtful if the latter is an earthquake indication.

HAKODATE or **41.** Time 9.22.14. The motion was violent. Direction ENE, WSW and N & S. A second shock was felt a few minutes later.

SAPORO or **42.** Time 9.22.32. Chief motion NE. SW. The amplitude of motion as indicated by a pendulum seismograph (Fig 7) may have reached 7^{mm}. The shock is said to have been severe. The duration was over a minute. It commenced as a series of tremors in a direction N 17 E, followed by a lurch N 28 E, when the pointer was thrown off the plate on which it was intended to write its record.

Records from other places were as follows:—

At **4.** 10.10 P. M. feeble—**7.** 10.20 feeble SW—**8.** 10.10 P. M. pretty strong—**10.** 9.55 P. M. pretty strong E.—**11.** 9.50 P. M. feeble SE—**12.** 10.5 P. M.—**13.** 10.0 P. M. feeble SW—**20.** 9.35 P. M. feeble.—**44.** severe.

Origin of the Shock.

From the severity of the shock at Hakodate and Saporo as compared with the slight motion experienced in the south, together with a consideration of the places where the disturbance was observed, it might be inferred that the origin was beneath the ocean eastwards from Hakodate. It might also be argued that this origin was nearer to Hakodate than Saporo, the disturbance having been more severe at the former of these places.

From the directions given by seismographs at Tokio, Chiba and Yokohama, in conjunction with the principal direction indicated by the seismograph at Saporo, it would appear that the origin might either be near the Volcano of Kumagatake

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on the shore of Volcano Bay in 140°.20′ E. Long. and 42°.10′ N. Lat, or in 142°.20′ E. Long. and 41°.40′ N. Lat. Using a time hyperbola between Hakodate and Saporo in conjunction with a direction given by the Saporo instrument, we should conclude that the origin was farther to the eastward, in about 142° E. Long. and 42°. N. Lat.

Working with the aid of the time data alone, either by the method of circles or that of hyperbolas, the origin is thrown still farther to the east to about 144° 15′ E. Long. and 41° N. Lat.

These three possible origins all lie on an ESE line about 150 miles long, drawn from the head of Volcano Bay.

Of these origins the second is the one most probably correct. The second and third origin it may be observed lie on the flanks of the continuation of a great anticlinal crossing Yezo in a NW SE direction. This is indicated on map 124 by a dotted line.

Velocity of Propagation.

Assuming the time observations to be correct the disturbance, which must have passed between Tokio and Yokohama in what was practically a straight line, did so at a rate of over 4500 feet per second. Assuming the origin to have been near the head of Volcano Bay the shock must have travelled from the Hakodate homoseist on to Saporo at a rate of more than 8600 feet per second.

With other assumptions as to the origin, we obtain different velocities along different lines, some of which are as much as 10,000 feet per second.

The general conclusions are that the velocities of propagation are different along different lines, being greatest between points which are near the origin. The variations in velocity lie between 9000 and 4000 feet per second.

These calculations are based on the assumption that the shock first reached Hakodate and that it was felt 18 sec later at Saporo, 128 sec later at Tokio and 149 sec later at Yokohama.

It must be observed that if the direction observations were neglected and it was assumed that the various time observa-

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tions were correct, and also that the earthquake travelled in all directions with the same velocity as it travelled between Tokio and Yokohama, a fourth possible origin might have been calculated.

—— 8 ——

1881. Nov. 5.

25. 1.04 A. M. feeble. W.

—— 9 ——

Nov. 10.

25. 6.15 A. M. feeble.

—— 10 (Map 111) ——

Nov. 11 9.10.56.

Tokio. *Yamato Yashiki.* Time 9.10.56 and 9.11.21 A. M. Direction NNW 40′, ENE 30′, ESE 30′.

Chiba. Time 9.11.0 Pendulum seismograph (Fig. 8) indicated a single motion of 1^{mm} N 60° E and a series of motions of about $.1^{mm}$ N 20 E.

Other places where the shock was felt were:—

At **2.** 10.9 A. M. feeble—**6.** 9.25 A. M.—**12.** 9.50 P. M. **39.** 9.10 A. M.

Origin. From the distribution of places at which the disturbance was felt, and the indicated directions, it is probable that the shock originated beneath the ocean about 400 miles NNE of Tokio or in the same locality as Number 7.

—— 11 ——

Nov. 11.

At **2.** 11.24 P. M.

—— 12 ——

Nov. 12.

At **39.** 3.30 A. M.

—— 13 ——

Nov. 15.

12. 3.10 A. M. feeble.

—— 14 (Map 39) ——

Nov. 15. 9.47.32 P. M.

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TOKIO. *Yama Guchi.* A slight shock at 9.43.54 a pendulum seismograph (Fig. 9) indicated a maximum motion of .5^{mm} in a direction N 8° E. A double bracket seismograph (Fig. 11) showed 3.5 vibrations per second. These are too much drawn out by the rapid motion of the plate to indicate direction. A pair of heavy ring bracket seismographs indicated an extremely slight motion.

There was no vertical motion.

A pair of conical pendulums indicated a very slight motion extending over about 25 sec. The first 10 seconds of this are shown in (Fig. 10). There were about 3.5 vibrations per second.

Yamato Yashiki. 9.47.32 P. M.

Yokohama. Mr. Owston observed at 9.43.23 P. M.

A pendulum instrument writing on a moving plate gave very slight ripples in a NS direction having an amplitude of about .1^{mm}.

The shock was also felt at;—

2. 10.23 P. M. duration 5'. 11.17 P. M. duration 7' both shocks being feeble.—**4.** 9.50 P. M.—**6.** 9.45 P. M. and 9.50 P. M.—**7.** 11.10 P. M. feeble SW.—**8.** 10.4 P. M. 10.9 P. M. and 11.0 P. M. The first two shocks SE and the last SW.—**9.** 10.5 P. M.—**10.** 10.15 P. M., feeble; 10.20, feeble; 11.20, pretty strong, and 11.22, feeble.—**11.** 10.43 P. M. strong, SE.—**2.** 10.20 P. M., strong.—**14.** 10.15 P. M.—**18.** 11.0 P. M. feeble—**46.** 10.20 P. M.

Origin. From the directions indicated by seismographs we should look towards the North for the origin of this disturbance. The fact that 4 shocks were felt at **10**, and 3 shocks at **8**, also point to an origin North from Tokio. At both **2** and **6** no shocks were felt. If we draw a NW SE line from between **10** and **12**, through **8, 6, 3,** down to **2** and then refer to the earthquakes before and after the one under discussion, we see that this was a line along which there was activity for several days. The greatest amount of activity being in the south near **4, 6** and **3.** The line it may be observed approximately follows the valley of the Tonegawa. The probability is that

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this series of earthquakes had their origin in the continuation of this line beneath the sea.

—— 15 ——

1881. Nov. 16.

6. 4.5 A. M.

—— 16 ——

Nov. 16.

6. 8.10 A. M.

—— 17 ——

Nov. 18.

4. 4.30 P. M. feeble.

—— 18 (Map 75) ——

Nov. 19.

4. 8.50 P. M.?—**8.** 9.55 P. M. SW.—**9.** 8.50 P. M.

—— 19 ——

Nov. 23.

46. At night.

—— 20 ——

Nov. 24.

2. 8.26 P. M. very feeble, duration 4'

—— 21 ——

Nov. 26.

Kiseradzu At 9.30 P. M. A pendulum seismograph showed a NS motion of 3^{mm}. (Fig. 13). The earthquake is doubtful.

—— 22 ——

Nov. 27.

25. 7.20 P. M, feeble, N. S.

—— 23 (Map 82) ——

Nov. 29.

5. 11.28 A. M. feeble—**6.** 11.0 A. M. feeble.

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—— 24 ——

1881. Dec. 3.

TOKIO. 9.16.43 A. M.

—— 25 ——

Dec. 3.

2. 11.25 P. M. very feeble.

—— 26 (Map 53) ——

Dec. 5.

17. 1.28 P.M.—**22.** 1.15 P.M. two feeble shocks from the west.—**38.** 1.26 P.M.

—— 27 ——

Dec. 5.

40. 1,30 P. M. (This may have been simultaneous with earthquake 26.

—— 28 ——

Dec. 8.

34. 1.10 P. M. SE.

—— 29 ——

Dec. 8.

7. 10.0 P. M., feeble, NW.

—— 30 (Map 32) ——

Dec. 9.

4. 8.5 P. M. feeble.—**6.** 8.0 P. M.—**7.** 10.0 P. M. NW—**8.** 9.30 P. M.—**9.** 9.0 and 9.1 P. M.—**10.** 9.5 and 9.10 P. M., both feeble—**12.** 9.25 P. M. very feeble.—**26.** 9.40 P. M. feeble.—**39.** 10.10 P. M.

—— 31 (Map 13) ——

Dec. 10.

34. 10.40 P. M.—**39.** 10.42.30 P. M. duration 2ˢ. NE and N moderate.

—— 32 (Map 79) ——

Dec. 11.

TOKIO. 11.5.14.

YOKOHAMA. A pendulum seismograph showed an E. W. motion of 1.5ᵐᵐ (Fig. 14).

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—— 33 ——

1881. Dec. 15.

34. 8.25 P. M. SW.

—— 34 ——

Dec. 18.

26. 4.50 A. M. very slight.

—— 35 (Map 74) ——

Dec. 19.

7. 9.0 P. M., feeble SE.—**10.** 8.25 P. M., feeble—**12.** 8.45 P. M. feeble.

—— 36 ——

Dec. 22.

12. 1.50 A. M. feeble.

—— 37 (Map 72) ——

Dec. 22.

6. 11.45 P. M.—**10.** 11.40 P. M. feeble.

—— 38 (Map 45) ——

Dec. 23. 4.40.10 A. M.

TOKIO. *Yama Guchi.* Time 4.37.6 as observed by watch and 4.37.54 as observed by a clock which was stopped.

A pendulum seismograph did not show any motion.

A pair of conical pendulums (Fig. 15) writing on a revolving drum gave the following record. Motion in a direction N 17 E commenced gently, reached a maximum in two or three seconds and practically died out in about 12 seconds. The motion at right angles to this N 73 W, commenced with three large vibrations and continued for fully 15 seconds. There appears to have been from 3 to 4 complete vibrations per second.

Yamato Yashiki. Time 4.40.10 A. M.

Yokohama. During the night three shocks were felt.

The largest gave with a pendulum seismograph a motion of about 2^{mm} in an ENE WSW direction.

CHIBA. The disturbance which was short and severe commenced at 4.34.56 lasting 20 seconds.

A pendulum seismograph (Fig. 12) gave a decided motion

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N 60 W with an amplitude of 1.5^{mm}. There were also N and S transverse motions.

The earthquake was also felt at,—

2. 5.0 A.M. duration 60^{sec}.—**4.** 4.35 A.M., feeble.—**6.** 4.30 A. M., strong.—**7.** 5.0 A. M. feeble, NE—**8.** 4.30 A. M.—**9.** 3.50 A. M.—**10.** 6.0 A. M. pretty strong.—**14.** 5.5 A. M.

Origin. It is probable that the origin of this shock was the same as that of Nov. 15 (No. 14).

—— 39 ——

1881. Dec. 24.

6. 5.40 P. M.

—— 40 ——

Dec. 25.

12. 10.5 A. M. pretty strong.

—— 41 (Map 5) ——

Dec. 25.

Saporo. Time 2.40.0 P. M. (local). Direction ESE WNW. Intensity slight.

Nemuro. Time 2.47.0 P. M. (apparent). A strong shock from the SW.

The shock was also felt at,—

39. 3.0 P. M.

—— 42 (Map 13) ——

Dec. 25.

39. 10.0 P. M.—34. 10.05 P. M.

—— 43 (Map 2) ——

Dec. 26, 1.12.30 P. M.

Tokio. *Yama Guchi.* Time 1.12.35 calculated from 12 o'clock gun fire. A short sharp push.

Conical pendulums (Fig. 16) writing on a drum started by the shock. The N 17° E motion consists of a few gentle ripples lasting about 8 seconds. The N 73 W motion can be traced for about 15 seconds. The movement is greater in this component than in the former. There were about 4.5 complete vibrations per second.

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The diagrams given by a pair of rolling cylinder seismographs on a revolving plate indicated motion extending over about 20 sec. Six seconds of the N 20 W motion is given in (Fig. 17). It is similar to the N 110 W motion. There were from 4 to 4.5 vibrations per second.

Yamato Yashiki. Time 1.12.30 P. M. Directions SSE 40′. SSW, 20′. WNW, 10′.

KAMAISHI. Time 1.13.40 (Telegraph time). The shock which was moderate was accompanied by a rumbling sound. Duration 10^{sec}. Direction about ENE.

This distrubance was also felt at,—

9. 1.30 P.M.—**10.** 1.30 P.M. strong—**13.** 1.30 P.M. feeble.—**14.** 1.30 P.M.—**17.** 1.0 P.M. feeble. **18.** 2.0 P.M. feeble—**26.** 1.20 P.M. strong. **27.** 2.0 P.M. strong—**28.** 1.30 P.M.—**29.** 2.50 P.M. pretty strong, W.—**30.** 2.25 P.M. N.W. —**31.** 2.0 P. M. pretty strong, N. E.—**32.** 1.44 P.M. pretty strong, duration one minute.—**34.** 1.23 P. M. S.—**39.** 1.13.40 P. M. duration 10^{s}, ENE, very moderate, a continuous rumbling heard.—**42.**

Origin. The origin of this shock is probably beneath the sea about 350 miles NE from Tokio. (see No. 7).

—— 44 ——

Dec. 28. 10.4.0 A. M.

Hama Saki. A sharp shock lasting about 15 seconds. Capt Carrew, who records this shock, remarks that it appeared to originate right under his vessel which was anchored in 5 fathoms of water.

—— 45 ——

Dec. 28.

38. 6.30 P. M, feeble.

—— 46 (Map 101) ——

Dec. 29.

Tokio 4.24.15 A. M. Directions WNW, 20′. SSE, 15′. Duration 25^{s}—**14.** 4.20 A. M.

—— 47 (Map 89) ——

Dec. 29.

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TOKIO 5.4.7 P.M. Directions WSW, 30′. SSW, 30′. SSE, 10′.

Yama Guchi. A long gentle earthquake. A double bracket seismograph gave a few ripples.

Yokohama. A pendulum seismograph (Fig. 18) appears to have given one swing East and West. Amplitude 1.7^{mm}.

This earthquake was also felt at:—

2. 5.49 P. M. feeble, duration 1^{m}. 20^{s}.—**25.** 6.0 P. M. feeble, E.

—— 48 ——

1881. Dec. 31.

25. 10.05 A. M. feeble. N.

—— 49 (Map 59) ——

Dec. 31 12.24.15. P. M.

TOKIO. *Yama Guchi.* Time 12.19.50. P. M.

Conical pendulums (Fig. 19). N 17 E motion can be traced as slight ripples over a period of about 15 seconds. There appear to have been about 5 complete vibrations per second. N 73 W motion is the better defined.

A Pendulum seismograph (Fig. 20) indicated a decided motion of .8^{mm} W 30 S. There were also transverse motions.

A vertical spring lever instrument (Fig. 21) indicated about 4 up and down movements per second.

Yamato Yashiki. Time 12.24.15 P. M.

YOKOHAMA. Mr. Talbot timed the shock at 12.27.56:

The motion was decided but not violent. A pair of brackets gave a clear diagram on a revolving plate.

A pendulum seismograph (Fig. 22) indicated motion in various directions, the North and South being the most provinent with an amplitude of 1^{mm}.

A second similar instrument in another part of Yokohama indicated a principal motion NNW.

CHIBA. Time 12.24.30 Duration 10^{sec}. Intensity slight.

This earthquake was also felt at,—

1. 0.35 P.M. feeble—**15.** 0.40 P.M. SW, duration 5^{sec}—**17.** 11.20 A.M.—**18.** 1.0 P.M. feeble—**20.** 0.26 P.M. feeble **21.** 0.30 P.M.—**22.** 12.0 very feeble W—**23.** 0.55 P.M. feeble. SW.

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—— 50 ——

1882. Jan. 2.

14. 3.0 A. M.

—— 51 (Map 96)——

Jan. 2. 5.47.26 P. M.

Tokio. *Yama Guchi.* The instruments at this place did not give the slightest record.

Shiba. The shock was felt by serval persons. A few seconds before the motion a sound was heard.

Yamato Yashiki. Time 5.47.26 P. M. Directions NNW 30′, WNW 20′, ENE 10′. Duration 16".

This appears to have been a shock only felt in certain parts of Tokio.

This shock was also felt at **1.** 6.15 P. M.

—— 52 ——

Jan. 5.

26. 11.0 A. M. feeble.

—— 53 (Map 75) ——

Jan. 5.

4. 10.10 P. M. feeble—**8.** 10.30 P. M.—**9.** 10.5 P. M.—**10.** 9.40. P. M. feeble, W.

—— 54 ——

Jan. 6.

40. 5.50 A. M.

—— 55 (Map 10) ——

Jan. 7.

35. 9.0 P. M. feeble, N—**36.** 9.45 P. M feeble.—**39.** 10.30 P. M.

—— 56 ——

Jan. 9.

29. 2.0 A. M. feeble, W.

—— 57 (Map 16) ——

Jan. 9.

Tokio. *Yama Guchi.* At 6.2.30 A. M. a distinct shaking was felt, lasting 60 seconds.

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Whether this was the same shock that was felt at a large number of places in North Nipon is doubtful, inasmuch as intermediate places were not disturbed.

This shock was also felt at,—**26.** 6.20 A. M. feeble—**27.** 6.30 A. M. feeble. NNE—**32.** 6.25 A. M. feeble but long—**33.** 5.54 A. M., pretty strong but long—**34.** 6.20 A. M. SE.—**35.** 7.0 A. M. feeble. S—**39.** 5.20 A. M. duration 1^{m}. NNE. moderate.

—— 58 ——

1882. Jan. 11.

29. 1.0 A. M. feeble, W.

—— 59 ——

Jan. 11.

39. Two shocks at 6.40 and 7.0 A. M.

—— 60 ——

Jan. 11.

8. 11.30 P. M.

—— 61 (Map 38) ——

Jan. 12. 12.0.55 P. M.

Chiba. A slight shock lasting 10 seconds took place at 12.0.55 P. M.

This shock was also felt at,—

4. 1.0 A. M. feeble.—**7.** 1.0 A. M. feeble, N E—**14.** 1.0 A. M.—**26.** 1.0 A. M. feeble.—**29.** 1.0 A. M. strong, S.

—— 62 (Map 65) ——

Jan. 12.

2. 0.8 P.M. feeble, duration 7 sec.—**3.** 11.50 A. M. feeble.—**9.** 0.20 P. M.

—— 63 (Map 30) ——

Jan. 13.

8. 8.30 A. M.—**9.** 8.37 A. M.

—— 64 (Map 105) ——

Jan. 14. 7.34.15.

Tokio. At Yama Guchi, Shiba and Shinagawa the shock does not appear to have been felt although numerous enquiries

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were made. At the Kobu-dai-gakko, in Azabu, and at Komaba it was slight. In a club in Igura it was so severe that members were on the point of leaving the building.

Yamato Yashiki. 7.34.17. P. M. Directions WNW 10′, WSW 10′.

YOKOHAMA. Time 7.34.17. P.M.

The motion as indicated by a pendulum seismograph (Fig. 20) was first N and S. This was followed by an E and W. movement the amplitude of which was about 1^{mm}.

CHIBA. Time 7.35.7. Intensity was slight. Duration about 5 seconds.

The shock was also felt at:—**12.** 7.50 P.M. very feeble.

Origin. From the fact that the shock was felt in Yokohama at the same time that it was felt in Tokio, the origin ought to be on a line which bisects the line joining Tokio and Yokohama at right angles. Assuming the principal direction at Yokohama to have been E W, we obtain an origin on the east side of Yedo Bay near to a place at which several severe shocks have been known to originate. This origin would agree with one deduced from the area over which it is known the disturbance was felt. The data which do not agree with this determination are the directions observed in Tokio and the time observed at Chiba.

—— 65 ——

1882. Jan. 15.

NEMURO or **44.** 4.40 P.M.

—— 66 ——

Jan. 16.

NEMURO or **44.** 4.33 A.M. On this date there was a slight shock at 39.

—— 67 ——

Jan. 16.

NEMURO or **44.** 3.27 P.M. On this date there was a slight shock at 39.

—— 68 ——

Jan. 16.

KAMAISHI or **39.** A slight shock from the NNE.

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—— 69 ——

1882. Jan. 18.

34. 1.15 P.M. E.

—— 70 ——

Jan. 18.

35. 10.30 P. M. feeble.

—— 71 (Map 31) ——

Jan. 19.

9. 6.40 A. M—**10.** 6.20 A. M. feeble.—**26.** 6.9 A. M.

—— 72 ——

Jan. 21.

10. 3.40 A. M. feeble.

—— 73 ——

Jan. 22.

NEMURO or **44.** 9.41 A. M.

—— 74 ——

Jan. 22.

NEMURO or **44.** 11.36 A. M.

—— 75 ——

Jan. 23.

39. 1.50 A. M. duration 3", strong, NNE.

—— 76 (Map 15) ——

Jan. 25.

29. 1.0 A. M. feeble, N S—**32.** 1.56 A. M. feeble and short—**34.** 2 A.M. E.

—— 77 ——

Jan. 25. 8.22.20 A.M.

KAMAISHI or **39.** A moderate NNE shock at 8.22.20 A. M.

—— 78 (Map 109) ——

Jan. 25.

TOKIO. Yamato Yashiki. Time 3.47.27 P. M. Duration 50 sec.

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CHIBA. Time 3.47.41. The shock, which was slight, lasted 35 seconds.

This earthquake was also felt at—**2.** 3.0 P. M.—**4.** 3.36 P. M. feeble.—**5.** 3.30 P. M.—**8.** 4.15 P. M.—**9.** 3.50 P. M.—**10.** 4.10 P. M. feeble.—**13.** 3.50 P. M.—**26.** 4.30 P. M. feeble.—**29.** 3.40 P. M. feeble N W—**39.** 3.10 or 3.22.20 A. M.? Duration 13ˢ. NNE moderate.

—— 79 ——

Jan. 25.

10. 8.30 P. M. feeble.

—— 80 ——

Jan. 25.

26. 11.20 P. M. very feeble.

—— 81 (Map 12) ——

Jan. 26.

33. 8.0 A. M.—**39.** 7.40

—— 82 ——

Jan. 28.

12. 1.5 A. M. pretty strong.

—— 83 (Map 115) ——

Jan. 28.

14. 11.50 P. M.—**26.** 12.0 P. M. very feeble.

—— 84 (Map 40) ——

Jan. 29.

TOKIO. 1.6.0 A. M.

15. 1.2 A. M. duration one minute.

—— 85 (Map 119) ——

Jan. 29.

TOKIO. *Yama Guchi.* Time 12.6.18 A. M. a slight shock.

A pendulum seismograph (Fig. 24) indicated a motion of .4ᵐᵐ N 25 E.

Yamato Yashiki. Time. 12.6.0 A. M. Directions ENE, 1′.20″. NNW, 30′. NNE, 20′. ESE, 10′. Duration 17ˢ.

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CHIBA. A very slight shock was felt at 12.3.23 A. M.

YAMAGATA. Here three shocks were felt. The first of these which was strong moved N and S.

—— 86 ——

1882. Jan. 29.

10. 11.40 P. M.

—— 87 (Map 113) ——

Jan. 29.

33. 12.40 P. M.—**34.** 11.20 P. M. SE.—**38.** 10.40 P. M. feeble.

—— 88 (Map 18) ——

Jan. 30.

9. 3.45 A. M.—**26.** 3.24 A. M. feeble.—**27.** 3.5 A. M. pretty strong, NE—**28.** 3.0 A.M.—**29.** 4.0 A.M. strong—**30.** 2.20 A. M. NW—**32.** 3.24 A. M. feeble but long—**39.** 2.30.

—— 89 (Map 17) ——

Jan. 31.

26. 5.30 P. M. very feeble.—**27.** 4.45 P. M. feeble E—**29.** 5.30 P. M. strong, W—**32.** 3.25 and 5.25 P. M. both feeble—**33.** 5.10 P. M. feeble—**34.** 5.20 P. M. S—**36.** 5.30 P. M.—**40.** 5.35 P. M.

—— 90 ——

Feb. 1.

TOKIO. Early in the morning a strong shock was felt at Surugadai. It was not felt at Yamato Yashiki nor at Yama Guchi.

—— 91 (Map 19) ——

Feb. 1.

9. 6.20 A. M.—**26.** 7.20 A. M. feeble—**27.** 7.40 A. M. feeble, E—**29.** 4.0 A.M. feeble, S.—**32.** 7.50 A.M. feeble.—**39.** 5.10.0 A. M. duration 3ˢ. NNE, strong. Pheasants screamed.

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—— 92 (Map 73) ——

1882. Feb. 1.

8. 1.40 P. M.—**9.** 0.15 P. M.—**10.** 1.10 P. M. pretty strong.

—— 93 ——

Feb. 3.

26. 5.30 A. M. very feeble.

—— 94 ——

Feb. 3.

NEMURO or **44.** 6.20 A. M.

—— 95 ——

Feb. 3.

8. 8.30. P. M.

—— 96 ——

Feb. 4.

NEMURO or **44.** 10.15 A. M.

—— 97 (Map 110) ——

Feb. 6.

TOKIO. *Yama Guchi.* Time 5.3.15 A. M.

A pendulum seismograph (Fig. 25) gave a slight motion .2^{mm} N 10 E.

A rolling cylinder seismograph (Fig. 26) indicated motion of .15^{mm} chiefly in an E W direction. The period was .33 sec. Duration 20 sec. Only 10 seconds of motion are shown in Figure. A Double Bracket on a moving plate (Fig. 27,) showed from 2.5 to 3.5 vibations per second. Amplitude about. 2^{mm}. The direction of motion was E 23 S. Only 4 seconds of the record is shown. A pendulum seismograph writing on a moving plate gave the diagram shown in Fig. 28. Owing to the slowness of the earth's motion there seems to have been a swing in the pendulum.

Yamato Yashiki. Time 5.0.30 A. M.? Directions NNW, 10′. NNE 10′.

Yokohama. Time 5.3.38 A. M.

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Other places at which this earthquake was felt, were;—**1.** 5.30 A.M. feeble.—**2.** 5.0 A. M. feeble, duration 9ˢ.—**14.** 5.0 A. M.—**25.** 4.0 A. M. feeble, NW.—**26.** 5.10 A.M. feeble.—**24.** 3.50 A. M. feeble, E.

Origin. The most probable origin for this shock is near the NE end of Yedo Bay.

—— 98 ——

1882. Feb. 9.

NEMURO or **44.** 10.3 A.M.

—— 99 ——

Feb. 10.

NEMURO or **44.** 5.37 P.M.

—— 100 ——

Feb. 11.

40. 11.55 P.M.

—— 101 ——

Feb. 12.

1. 5.0 A.M. feeble.

—— 102 (Map 66) ——

Feb. 12.

TOKIO. *Yamato Yashiki.* 2.49.0 P. M. Direction NNW 10′. Duration 53ˢ.
7. 3.18 P. M., feeble, NW.

—— 103 ——

Feb. 13.

NEMURO or **44.** 0.14 A.M.

—— 104 ——

Feb. 13.

2. 2.55 P. M., feeble, duration 3ˢ.

—— 105 ——

Feb. 14.

8. 7.30 A.M.

—— 106 ——

Feb. 14.

40. 11.15 and 11.20 A.M.

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—— 107 ——

1882. Feb. 14.

2. 10.36 P.M. duration 16ˢ.

—— 108 ——

Feb. 15.

2. 4.31.0 A.M. feeble.

—— 109 ——

2. 5.8.0 A. M. duration 3ˢ.

—— 110 ——

2. 10.3.0 P. M. duration 4ˢ.

—— 111 ——

Feb. 16.

NEMURO or **44.** 5.0.0 A. M.

—— 112 ——

Feb. 16.

CHIBA. 6.59.21 A.M. severe but short.

—— 113 (Maps 57 and 91) ——

Feb. 16.

TOKIO. *Yamato Yashiki.* About 8.0.0 A.M.

2. 7.2 and 7.50 A. M. First shock lasted 31ˢᵉᶜ and the second 1 minute.—**3.** 7.0 and 7.52 A. M.—**17.** 8.30 A. M. S, short.—**18.** 8.0 A. M. feeble.—**21.** 8.50 A. M.

CHIBA 7.52.7 A. M. slight, duration 2ˢ.

Probably two shocks (see maps 57 and 91)

—— 114 (Map 92) ——

Feb. 16. 5.33.13 P.M.

TOKIO. *Yama Guchi.* Time 5.32.16. The only record obtained was from a pendulum seismograph. This was approximately N and S. amplitude .2ᵐ. The shock seems to have been felt very differently in different parts of Tokio.

Yamato Yashiki. Time 5.33.13 P. M. Direction ENE 1° Duration 45ˢ.

Yokohama. Time 5.31.54.

Chiba, Time 5.33.48 P. M. This was the most severe of a series of shocks. The series was as follows.

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1882. Feb. 16.	6.59.21 A. M. severe, lasted 3ˢ			
	7.52.7 A. M. slight	„	2ˢ	(see 113)
	5.33.48 P. M. very severe			
	11.51.45 or 11.31.45 P.M. lasted 20ˢ			(see 115)
Feb. 17.	5.57.43 or 5.37.43 P.M.			(see 116)
	9.30.46 P. M. very slight	„	4ˢ	
18	5.49.53 rather severe	„	2ˢ	(see 120)

A pendulum seismometer indicated a motion N 35 E, amplitude .7ᵐᵐ (Fig. 29)

The shock was also felt at:—

2. 5.30 P. M. duration 1ᵐ—**3.** 5.35 P.M. strong—**4.** 5.20 P. M. feeble—**8.** 5.40 P. M.—**20.** 5.33 P. M. feeble.

Origin. The best data for the determination of the origin are the time observations at Tokio and Yokohama, the direction observation at Chiba, and the area over which the shock was felt. These data may be taken in conjunction with the area over which previous and succeeding disturbances were felt.

The conclusion is that the origin lay 5 or 10 miles to the eastward of Yokohama or Kanagawa.

Velocity. The velocity with which the shock travelled from the Yokohama homoseist on to Yokohama appears to have been about 2800 feet per second.

—— 115 (Map 83) ——

Feb. 16.

Chiba. 11.51.45 or 11.31.45 P. M. Duration 20ˢ. A pendulum seismograph (Fig. 30) indicated motion N 35 E with an amplitude of .9ᵐᵐ.

The shock was also felt at:—

2. 11.0 P. M. duration 5ˢ—**3.** 11.58 P. M.

—— 116 (Map 85) ——

Feb. 17.

Chiba 5.57.43 or 5.34.43 P. M.?

The shock was also felt at:—

2. 3.36 and 5.10 A. M. duration each 4ˢ—**3.** 4.30 A. M.

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—— 117 (Map 29) ——

1882. Feb. 17.

26. 3.15 P. M. feeble—**27.** 3.20 P. M. feeble, NE—**29.** 3.9 P.M. feeble, N—**30.** 4.0 P. M. feeble, NNW.

—— 118 ——

Feb. 17.

CHIBA. 9.30.46 P. M. very slight. Duration about 4 sec.

—— 119 (Map 83) ——

Feb. 18.

2. 3.0 P. M. duration 5s.—**3.** 3.35 P. M.

—— 120 (Map 87) ——

Feb. 18.

CHIBA 5.49.53 P. M. Rather severe. Duration about 2sec.

A pendulum seismograph (Fig. 31) indicated a motion N 40 E with an amplitude of 1mm. The origin of this shock is probably the same as numbers 114 and 115.

YOKOHAMA 5.50.18 P. M. slight. This shock was also felt in Tokio, and at:—

1. 6.0 P. M. feeble—**2.** 6.5 P. M. duration 1m.5s.—**3.** 6.10 P. M.—**4.** 5.40 P. M. feeble—**5.** 5.30 P. M. feeble.

—— 121 (Map 91) ——

Feb. 18.

TOKIO 11.54.0? P. M. Directions ENE 20′, NNE 10′. Duration 1m. 3s.

2. 11.20 P. M. duration 40s—**3.** 8.54 and 11.0 P. M. The last shock rather strong.

—— 122 (Map 86) ——

Feb. 19.

2. 1.0 A. M. and 4.20 A. M. First shock duration 20s. and the last 50s.—**3.** 2.30 3.55 and 4.30 A. M.—**4.** 1.30 A. M.

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feeble—**5.** 1.45 and 4.30 A. M. both feeble—**21.** 1.15 A. M.

—— 123 ——

1882. Feb. 19.

2. 7.5 A. M. duration 10ˢ.

—— 124 ——

Feb. 19.

2. 3.40 P. M. duration 5ˢ.

—— 125 ——

Feb. 20.

YOKOHAMA 5.54.54 A. M. very slight,

—— 126 ——

Feb. 20.

NEMURO or **44.** 5.10 P. M.

—— 127 ——

Feb. 22.

TOKIO. *Yama Guchi.* 5.42.24 A. M.

—— 128 ——

Feb. 22.

TOKIO. *Yama Guchi.* 4.8.41 P. M.

—— 129 (Map 88) ——

Feb. 22.

TOKIO. *Yamaguchi.* 6.54.0 P. M. A pendulum seismograph gave a small diagram.

CHIBA. A pendulum seismograph indicated 1^{mm}. of motion ENE.

YOKOHAMA. A pendulum seismograph indicated 2.5^{mm} of motion EW.

Other places at which the disturbance was felt were:—
2. 6.30 P. M. feeble, duration $1^{m}.3^{s}$—**4.** 6.50 P.M. feeble.

—— 130 ——

Feb. 26.

41. 9.9.4 P. M. very slight (?)

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—— 131 ——

1882. Feb. 27.

22. 3.30 A. M. pretty strong, W.

—— 132 ——

Feb. 27.

34. 11.5 A. M. S.—**44.** 11.5 A. M.

—— 133 ——

Feb. 27.

NEMURO or **44.** 8.35 P. M.

—— 134 (Map 121) ——

March 1st 1.49.40 A. M.

TOKIO. *Yama Guchi.* Time 1.49.2 A. M. A bracket seismograph (Fig. 32) on a revolving plate indicated an East and West motion lasting about 20 sec. The period was .25 sec. The North and South motion was similar to the East and West only slighter.

Yamato Yashiki. 1.49.40 A. M. Direction ENE 1°, NNW, 19′. Duration 11 sec.

YOKOHAMA. From a bracket machine (Fig. 33) recording on a revolving plate it is seen that the motion is chiefly N 10 W and S 10 E. Its duration was about 30^{sec}. Maximum amplitude $.2^{mm}$. The period was .25 sec.

A bracket machine on a straight plate (Fig. 34) indicated a motion extending over about 40 seconds. At the commencement the N 15 W component is the larger, but at the 4th 6th and 12th second of the disturbance the N 75 E component is the larger. The chief direction of motion appears to have been about NW. SE. The period at the commencement of the disturbance was .28 sec, but this increased towards the end to nearly 1 sec.

A pendulum on a moving plate (Fig. 35) gave an irregular diagram, only part of which is reproduced. A lengthening in period may be observed about the 17, 18 and 19th second, as in the preceeding diagram.

As timed by Mr. Talbot 1.48.55. Duration about 20 sec. From the above it appears that the shock was felt in Yokohama about 7 sec. *before* being felt in Tokio.

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YAMAGATA. At 2.9.0 A. M. a rather severe shock lasting about 12 seconds was felt. The direction was about East and West.

The shock was also felt at,

2. 1.10 A. M. feeble, duration 6s.—**4.** 1.50 A. M. feeble **6.** 1.0 A. M.—**7.** 2.0 A. M. feeble, SW—**9.** 2.59 A. M.—**10.** 2.40 A.M. feeble—**14.** 1.0 A.M.—**15.** 1.40 A. M. feeble—**20.** 1.50 A. M. feeble—**21.** 1.50—**34.** 2.15 A. M., E.—**36.** 0.10 A. M.

——.135 (Map 50) ——

1882. March 1st 3.28.10 A. M.

TOKIO. *Yama Guchi.* At 3.28.2 A. M. A distinct movement being felt for 83 seconds.

Of a series of columns marked 1 to 8, (number eight being the largest) number 1 fell N 40° E, number 3 and 5 fell N 85 E. Two small inverted cones fell about N 40 E.

A pendulum seismograph (Fig. 36) commenced with movements of about .7mm approximately E and W. These were followed by two strong lurches E 20 S of about 3.5mm. The next movement which was still stronger was SE. It threw the recording pointers off the smoked plate. A second similar seismograph (Fig. 37) shewed motion in all directions but the largest motions of about 7mm had a decided direction of E 23 S.

A double bracket instrument shewed motion in the same direction. A bracket seismograph on a revolving plate (Fig. 38) gave a diagram extending over 55mm. The portion of this diagram reproduced in Fig. 38 extends from the 10th to the 20th second of the disturbance. The N S component was altogether small. The E and W component was small for the first 10 seconds. About the 13th second after the commencement there was a strong lurch to the SSE. There was a similar lurch at the 18th second. At the commencement of the disturbance the period was .16 sec. but at the end 2.8 sec.

This disturbance was a typical earthquake, commencing with tremors and a shock, and ending with irregular vibrations. These latter died out with a very slow period.

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Dai Gaku. Prof. Ewing's seismograph indicated that the motion extended over a period of about 3 minutes. It commenced as short waves with a period of .17". The greatest displacement which is E and W is about 5^{mm}. The greatest back and forth motion occupied .8". As the disturbance died out the period increased. The North and South component was not recorded. The East and West motion gave a maximum velocity of 19.6^{mm} per sec. and a maximum acceleration of 154^{mm} per sec. or $\frac{1}{64}$ of g.

Yamato Yashiki. At 3.28.10 A. M. Duration 32". Direction ENE 6°4', NNW 2°, NNE 1°10'.

YOKOHAMA. By Mr. Talbot at 3.29.05. As noted by Mr. Favre Brandt by the stoppage of a clock, at 3.30.22.

A pendulum seismograph indicated a NW motion but as the pointers were thrown off the plate a complete diagram was not obtained. A good diagram was however obtained from the friction pointer of the pendulum, indicating a principal motion to the WNW, (see Fig. 39).

A similar seismograph in another part of Yokokama also showed a principal WNW motion.

A bracket seismograph on a revolving plate (Fig. 40) registered the motion as two components, one being N 10 W and the other N 80 E. The duration of the motion was nearly 3 minutes. Up to the 90th second both components of the disturbance are shown, but from the 91st to the 153rd second only the N 10 W motion is given. The N 10 W commenced with a series of minute waves with a period of .25 sec. lasting 18 seconds. At the 18th second an extremely irregular motion set in consisting of shocks or jolts with intervening small waves. Large jolts may be observed at the seconds, indicated by the following numbers,—24, 30, 33, 36, 40, 46, 49, 56, 64, 70, 73, 75. Other violent movements are to be seen on the diagram, but they are not so pronounced. The movement at the 49th second is the largest of the series. Its direction is towards the north. The time taken to make this movement which has an amplitude of 2.5^{mm} was about $\frac{1}{3}$ second. If the motion is simple harmonic the maximum velocity is 11.78^{mm} and the maximum acceleration

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56^{mm} per sec., per sec. A curious point worthy of attention is that whenever the ground has moved suddenly towards the north there has been an equally sudden return, whilst when the ground has moved towards the south, before swinging back towards its normal position, there has been a pause, as is indicated by the flat tops to some of the waves. In some instances as in the N 10 W motion at the 64th second, this pause exceeded a second in its duration.

The period of the small waves which are interposed between and superimposed on the large waves, is about .4 seconds. At the end of the disturbance we find waves having a period of at least 2 seconds, that is to say eight times slower than they were at the commencement.

Chiba. A pendulum seismograph (Fig. 41) gave a clear diagram indicating N and S motion.

The shock was observed at 3.28.55 A. M. lasting 32 seconds.

From the above it would appear that the shock was first felt in Tokio, 53 seconds later at Chiba, and 10 seconds still later at Yokohama. At 3.33.0 A. M. a second shock was felt in Tokio, perhaps indicating that the origin was near this place.

The disturbance was also felt at the following places.—

1. 3.30 A. M. pretty strong—**2.** 3.40 A. M. strong, duration 2^{m}.12^{s}—**4.** 3.25 A. M. feeble—**5.** 3.28 A. M. strong—**6.** 3.25 A. M.—**7.** 3.20 A. M. strong, SE.—**8.** 4.0 A. M.—**9.** 3.40 A.M.—**10.** 3.0 A.M. pretty strong.—**13.** 3.25 A.M. pretty strong—**14.** 3.25 A.M.—**15.** 2.30 A.M.—**17.** 3.0 A. M. long.—**20.** 3.30 A. M. feeble.—**21.** 3.25 A. M.—**25.** 3.0 A. M. pretty strong. SW. duration 3^{m}.—**26.** 3.50 A. M. pretty strong, long.—**27.** 3.30 A. M. pretty strong, NE.—**29.** 4.0 A.M. strong. W.—**30.** 3.30 A. M. W.—**32.** 3.40 A. M. strong and long.—**39.** 3.5 A. M. moderate.

—— 136 (Map 75). ——

1882. March 1st.

4. 8.25 A. M. feeble.—**8.** 8.0 and 8.10 A. M.—**9.** 8.10 A. M.—**10.** 9.0 A. M. feeble.

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—— 137 (Map 33) ——

1882. March 1. TOKIO 2.7.0 P. M.

4. 2.10. and 3.25 P. M. The last shock pretty strong.—**8.** 1.40. P. M.—**26.** 2.0 P. M. very feeble—**29.** 1.0 P. M. feeble. W.

—— 138 ——

March 1.

10. 6.0 P. M. feeble.

—— 139 (Map 26) ——

March 1.

26. 8.10 P. M. very feeble—**29.** 9.0 P. M. feeble W.

—— 140 (Map 118) ——

March 1.

10. 10.0 P. M. feeble—**25.** 11.0 P. M. very feeble.

—— 141 ——

March 2.

29. 1.30 A. M. feeble. W.

—— 142 (Map 24) ——

March 2.

5. 6.0 A. M. feeble—**26.** 6.10 A. M. very feeble.

—— 143 (Map 28) ——

March 2.

26. 8.15 P. M. feeble.—**27.** 9.20 P. M. feeble, NW.—**29.** 9.0 P. M. feeble. S. —**32.** 9.13 P. M. feeble.

—— 144 (Map. 15) ——

March 3.

29. 7.0 A. M.? feeble. W.—**34.** 7.10 P. M.? SE.

—— 145 ——

March 3.

NEMURO or **44.** 10.30 A. M.

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—— 146 ——

1882. March 4.

10. 10.0 P. M. feeble.

—— 147 ——

March 6.

1. 7.30 A. M. feeble.

—— 148 ——

March 6.

31. 4.2 P. M. feeble. NE.

—— 149 ——

March 7.

NEMURO or **44.** 0.54 P. M.

—— 150 (Map 42) ——

March 7th 11.5.56

TOKIO. *Yama Guchi.* At 11.4.40 or 11.4.45 P. M.

A pendulum seismograph (Fig. 42) showed a motion in all azimuths the maximum amplitude being .5^{mm}. One principal vibration is in a direction E 20 S.

In the record given by a bracket seismograph (Fig. 43) the motion extended over 40 seconds. The E and W motion which is the most prominent commenced first. The N and S motion is not noticeable until the 10th second. The period is .22 sec.

Yamoto Yashiki. At 11.5.56 P. M. Direction NNW 1°.50′, ENE 1°.30′, NNE 50′, ESE 10′, Duration 40″.

YOKOHAMA. Mr. Talbot did not feel this shock. A pendulum seismograph (Fig. 44) showed a decided motion of 1.2^{mm} N 23 E.

CHIBA. A pendulum seismograph (Fig. 45) showed a decided motion of .8^{mm} N 72 E.

YAMAGATA. The shock lasted 5 or 6 sec. and appeared to be N and S.

KAMAISHI. Many shocks between the 1st and 13th of March.

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This earthquake was also felt at,—

1. 11.15 P. M. feeble.—**4.** 11.3 P. M. feeble—**7.** 11.0 P. M. feeble, S.—**8.** 11.20 P. M. feeble—**9.** 11.50 P. M.—**10.** 11.5 P. M. strong.—**13.** 10.55 P. M. pretty strong.—**21.** 11.20 P. M.—**22.** 11.30 P. M. duration 7^{m}. N.—**26.** 11.0 P. M. feeble—**27.** 11.0 P. M. feeble E—**29.** 10.30 P. M. feeble.

—— 151 ——

1882. March 8.

6. 1.0 A. M., very strong.

—— 152 (Map 108) ——

March 8.

21. 2.25 A. M.—**22.** 2.15 A. M. duration 2^{m}.

—— 153 (Map 116) ——

March 8.

25. 10.45 A. M. feeble E.—**26.** 11.0 A. M. very feeble.

—— 154 (Map. 3) ——

March 8th 4.15.7 P. M.

TOKIO. *Yama Guchi.* At 4.15.8 P. M.

A bracket seismograph (Fig. 46) indicated a motion extending over 47 sec. The greatest motion was about .1^{mm} the period being .33 sec. The first few seconds the motion which was principally E W was so slight that it was barely visible.

A pendulum seismograph (Fig. 47) showed motion in all azimuths. Two of the principal motions have directions N 27 E and N 60 E. Fig. 48 shows two of the curious curves traced out by the pointers of the seismograph which are clearly visible on the original smoked glass plate.

A pendulum seismograph on a moving plate gave the diagram shown in Fig. 49. The diagram shown at the 31st second was traced when the motion of the plate had ceased. The period appears to have been about .5 sec.

Yamato Yushiki 4.15.07 P. M. Direction ENE 1°.20′, NNW, 50′. NNE 5′. Duration 1^{m}.20^{s}.

YOKOHAMA. At 4.18.30 or by stopping of a clock at 4.18.18 P. M.

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A bracket seismograph on a revolving plate (Fig. 50) gave a diagram during a period of 2½ minutes. Only the 1st sixteen seconds of this is reproduced. The disturbance commenced with a series of small waves with a period of .16 sec. At the 9th second the period became .25 sec., whilst at the end of the disturbance it was still slower. The maximum amplitude does not appear to have exceeded 1^{mm}.

CHIBA. A pendulum seismograph (Fig. 51) indicated a motion of 1^{mm}, N 30 E.

KAWAISHI. At 4.15.0 P. M. The disturbance lasted about 15 sec. It was strong enough to cause a forge roll weighing 50 cwts to move back and forth on the ground.

HAKODATE or **41.** At 4.17.29 P. M. The shock lasted 4^{m}. 33^{sec}. The direction by the swing of a lamp was ENE to WSW. The lamp which was suspended by a chain 4 feet long after being once stopped got up a swing of 1 ft. 11 in. On the high ground the shock was not so severe. At the Observatory the time recorded was 4.12.14.

SAPORO or **42.** At 4.20.0 P. M. A slight East and West undulation.

This earthquake was also observed at,—

1. 4.5 P. M. pretty strong—**4.** 4.18 P. M. feeble—**6.** 4.30 P. M. strong—**7.** 4.45 P. M. feeble NW.—**8.** 4.40 P. M.—**20.** 4.16 and 4.18 P. M. both feeble.—**25.** 3.50 P. M. pretty strong—**26.** 4.20 P. M. pretty strong, long—**27.** 4.5 P. M. feeble SE.—**32.** 4.25 and 4.27 P. M. strong.—**33.** 3.45 P. M. pretty strong.—**34.** 4.15 P. M. S.—**35.** 4.0 P. M.—**36.** 3.45 P. M.—**40.** 4.30 P. M.—**41.** 4.16.10 P. M. and 4.19.29; the first shock, duration 45^{s}, sharp.—**42.** 4.13.32 duration 50^{s}., gentle. E. W.—**44.** 4.40 P. M.

—— 155 (Map 4) ——

1882. March 8. 11.54.50. P. M.

TOKIO. *Yamato Yashiki.* At 11.54.50 and again at 11.56.48. P. M. Direction of first shock, ENE 30′, NNE 20′ Duration 38^{s}. The duration of the second shock 22^{s}.

YOKOHAMA. A pendulum seismograph showed .8^{mm} of motion N and S. (Fig. 52.)

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HAKODATE or **41.** At 11.43.0 lasting 15 sec. and again at 11.45.38 lasting 8 sec. The shocks were sharp. At the observatory the shock was timed at 11.40.34. P. M.

SAPORO or **42.** At 11.42.0 P. M. two strong shocks lasting 40 sec.

This earthquake was also felt at,—

8. 11.30 P. M.—**9.** 11.20 P. M.—**10.** 9.5 P. M. feeble.—**32.** 11.54 and 11.56 P. M. pretty strong.—**33.** 11.40 feeble.—**34.** 11.20 P. M. SE.—**36.** 12.0 and 12.10, feeble.—**40.** 11.45 P. M.—**39.** 11.42. P. M. duration 40ˢ. NNE. moderate.

—— 156 ——

1882. March 9.

NEMURO or **44.** 8.12.0 A. M.

—— 157 ——

March 9.

34. 3.6 P. M. S.

—— 158 ——

March 9.

17. 4.45 P. M. pretty strong.

—— 159 ——

March 9.

1. 8.20 P. M. feeble.

—— 160 (Map 14) ——

March 9.

32. 9.30 P. M. feeble.—**34.** 9.15 SE.—**35.** 10.0 P. M.—**36.** 9.45 P. M. pretty strong.—**39.** 9.57.30 P. M. duration 10ˢ. moderate.

—— 161 (Map 123) ——

March 9.

10. 11.35 P. M. pretty strong.—**19.** 11.35 P. M. pretty strong, duration 1ᵐ.—**25.** 12.45 feeble W.—**33.** 11.20 and 11.40 P. M. feeble.

—— 162 ——

March 10.

2. 6.40 A. M. feeble.

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—— 163 ——

1882. March 10.

NEMURO or **44.** 7.30 A. M.

—— 164 ——

March 10.

30. 4.2 P. M. feeble.

—— 165 (Map 122) ——

March 10.

10. 10.40 P. M. pretty strong.—**19.** 10.40 P. M. pretty strong, duration 1^{m}.—**25.** 9.0 P.M. very feeble—**34.** 9.20 P.M. E.

—— 166 (Map 49) ——

March 11th 8.0.0 P. M.

TOKIO. *Yama Guchi.* By watch at 7.51.7 P. M. From automatic record of clock 7.51.22 P. M. The shock was violent and lamps and pedulums swung through considerable arcs.

A series of columns standing on a stone pedestal fell in various directions. The diminsions of these columns have already been given. The directions in which they fell were as follows.

No.	Cylinders	No.	Truncated cones	
1.	N 45 E of Iron	8.	N 96 E	of Iron
2.	N 120 E „ „	1.	N 27 E	of wood
3.	N 5 E „ „	2.	N 58 E	„ „
4.	N 45 E „ „	3.	N 130 E	„ „
5.	N 80 E „ „	4.	North	„ „
6.	Not set „ „	5.	N 90 E	„ „
7.	N 149 E „ „			

Number 4 fell on number 5, whilst number 3 fell on the top of 4 and 5.

From the indescriminate manner in which the columns fell it is evident that for this particular earthquake their records were of no value.

Yama Guchi. Two pendulum seismographs (Fig. 53 and 54) each indicated motion about E 40 S.

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From Fig. 53, the earth must have commenced with a series of tremors after which there was a sudden movement of about 3^{mm} towards the NW which was followed by a movement of nearly 7^{mm} towards the SE. The succeeding movement to the NW threw the pointer of its plate.

A pendulum seismograph on a moving plate (Fig. 55) shews that the earthquake commenced as tremors, followed by 4 heavy lurches the directions and amplitudes of which were as follows.

N 20 W	amplitude	3^{mm}.
S 20 E	„	6^{mm}.
N 20 W	„	8^{mm}.
S 23 W	„	6^{mm}.

These movements together with those which follow constitute a series of spirals, wriggles and irregular movements which can only be judged of by reference to the diagram which extends over a period of 17 seconds.

A double bracket seismograph (Fig 56) gave a diagram as irregular as that shewn in Fig 51. Points of resemblance are marked A B C D &c. in each of these two diagrams.

The NE SW loop shown at the 2nd second in each of these diagrams is remarkable. The multiplication in Fig. 52 is less than in Fig. 51. It may also be observed that the double bracket instrument was supported on a tall post the flexibility of which has influenced the character of the diagram.

A vertical spring lever seismograph (Fig. 57) indicated that there had been a slight vertical motion with a period of .14 sec. the amplitude not exceeding .1 or $.2^{mm}$.

Yama Guchi. A bracket seismograph (Fig. 58) indicated a principal motion E and W or as combined with the N S motion about ESE. The total duration was $1^{m}.20^{s}$. The motion commenced with small vibrations, with an amplitude of about $.1^{mm}$. Their period was .25 seconds and they continued for 10 seconds. These were followed by four strong lurches the maximum amplitude of which was not more than 6^{mm}. After this the disturbance died out as a series of irregular waves with a period of about 1^{s}. On these waves a number of small

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waves are superimposed. From the first three vibrations of shock marked a b c d, on the assumption that the motion was simple harmonic, we can make the following calculations. Let A equal half a semi oscillation or amplitude, T the time in seconds to traverse A, V the calculated maximum velocity and α the maximum acceleration in millimeters.

		A	T	V	α
a to b	outward motion	1.5^{mm}	$.75^{sec}$	13^{mm}	56^{mm}
c to d	" "	3.0	1.	18	54
b to c	inward "	2.5	.05	50	500

As the time taken to traverse from b to c can only be estimated approximately on the diagram, the values for V and α dependent on it must not be regarded as accurate.

Calculating ab and cd without any assumption as to the nature of the motion, we get for ab, V = 17 and α = 96 whilst for cd, V = 21 and α = 73.

This shock was on the verge of being destructive and one or two chimneys were slightly cracked.

Dai Gaku. Prof. Ewing's bracket seismograph indicated that the earthquake commenced as a series of gentle oscillations not exceeding 1^{mm} in amplitude and lasting 8 sec. After this there was a sudden lurch in a SE direction the amplitude of which was 7^{mm}. After this there were other vigorous motions, the maximum amplitude being 8^{mm}.

As the largest wave had a period of 0.7 sec the greatest velocity must have been 31^{mm} per second and the greatest rate of acceleration 280^{mm} per second per second or $\frac{1}{35}$ the value of gravity. These calculations are based on the assumption that the motion was simple harmonic. As the disturbance died out the period became longer. (see Trans. S. S. Vol. IV. p. 74).

Yamato Yashiki about 7.50.54 P. M. Direction ENE 11°.20′, NNE 9°.50′, NNW 9°, ESE 2°.30′. Duration $3^{m}.20^{s}$.

YOKOHAMA. As observed by Mr. Talbot at 7.51.33. The observation was probably made at the time of the big shock. By the stoppage of a clock Mr. Favre Brandt observed at 7.52.10 P. M. Two bracket seismographs were thrown off the plates on which they wrote their records. The N 75° E

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motion was in one case at least 12^{mm} and in the other at least 5.5^{mm}. The movements at right angles to this were respectively at least 13^{mm} and 7^{mm}. A possible principal direction resulting from these indications would be E 15° S.

A pendulum seismograph (Fig. 59) without muliplication gave a principal direction E 5° S with a maximum amplitude of 25^{mm}. Part of this motion will however be due to swinging. This diagram shows a curious complication of motions which the earth must have experienced.

CHIBA. A severe shock at 7.45.17 P. M. lasting 108 sec. A pendulum seismograph (Fig. 60) without multiplication indicated two strong movements of 10^{mm} N 15 E and N. These with their respective return motions correspond with the 4 lurches observed at other stations.

This earthquake was also felt at the following places:—

1. 7.47 P. M. pretty strong.—**2.** 8.5 P. M. pretty strong, duration 16'.—**4.** 7.50 P. M. pretty strong.—**5.** 8.20 P. M., feeble.—**6.** 8.0 P. M. strong.—**7.** 8.50 P. M. strong. SE.—**8.** 8.0 P. M.—**9.** 7.50 P. M.—**13.** 7.50 P. M. strong but short—**17.** 8.2 P. M. pretty strong.—**19.** 7.50 P. M. pretty strong.—**20.** 7.50 P. M. pretty strong.—**21.** 8.0 P. M.—**23.** 7.50 P. M. pretty strong. SW.—**24.** 7.50 P. M. duration 30'.—**25.** 7.55 P. M. strong.—**26.** 7.0 P. M. very feeble.—**27.** 8.10 P. M. feeble. E.—**29.** 10.0 P. M. feeble N.—**34.** 7.20 P. M.—**38.** 7.47 pretty strong.

—— 167 ——

March 12.

29. 2.30 A. M. feeble, W.

—— 168 ——

March 12.

10. 8.10 P. M. feeble.

—— 169 ——

March 12.

19. 11.20 P. M. feeble.

—— 170 ——

March 13.

36. 5.4 A. M. pretty strong.

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—— 171 (Map 76) ——

1882. March 13. Tokio 9.20.0 P. M.

4. 7.50 P. M. feeble.—**8.** 9.00 P. M.—**10.** 8.20.

—— 172 ——

March 13.

19. 11.30 feeble.

—— 173 ——

March 14.

25. 2.10 A. M. feeble.

—— 174 ——

March 14.

35. 6.40 A. M.

—— 175 (Map 90) ——

March 14. 9.48.52 A. M.

Tokio. *Yama Guchi.* A slight shock at 9.48.57 A. M. *Yamato Yashiki* at 9.48.52.

This earthquake was also felt at :—

2. 9.45 A. M. feeble, duration 3'.—**4.** 9.45 feeble—**25.** 9.45 A. M.

—— 176 (Map 93) ——

March 15.

Tokio 11.57.42 A. M.

4. 11.50 A. M feeble. Also at Saporo.

—— 177 (Map 63) ——

March 15.

8. 0.20 P. M.—**10.** 0.28 P. M. feeble.

—— 178 ——

March 15.

8. 9.0 P. M.

—— 179 (Map 117) ——

March 17.

2. 8.20 A. M. feeble, duration 3'.—**9.** 8.15 P. M.?

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—— 180 (Map 34) ——

1882. March 19.

TOKIO. *Yama Guchi.* At 9.25.49 A. M.

A pendulum seismograph (Fig. 61) gave a decided motion of 1^{mm} S 10 E. One of the special loops clearly visible in the original is shown in Fig. 62.

Yamato Yashiki. At 9.25.33 A. M. Directions ENE 2° NNW 1°.10′. NNE 40′. Duration 21 sec.

Dai Gaku. Prof. Ewing's seismograph indicated that the disturbance extended over nearly 4^{m}, the greatest displacement was about 2^{mm} and the mean period less than 1^{sec}. The period increased towards the end of the disturbance.

CHIBA. At 9.25.38. there was a slight shock lasting about 50^{sec}. A pendulum seismograph indicated a motion of 2^{mm}, N 25 E.

This earthquake was also felt at,—

1. 8.45 A. M. feeble—**2.** 9.30 A. M. feeble, duration 1^{m}.—**4.** 9.25 A. M. pretty strong—**8.** 9.00 A. M.—**25.** 9.20 A. M. feeble—**26.** 9.00 A. M. very feeble.

—— 181 ——

March 19.

29. 3.00 P. M. feeble N.

—— 182 ——

March 21.

36. 6.00 A. M.

—— 183 (Map 120) ——

March 24. TOKIO. *Yamato Yashiki.* 4.36.21 P. M. Direction ENE 20′, ESE 20′, NNE 10′, Duration 35″.

36. 4.45 P. M.

—— 184 ——

March 26.

SAPORO or **42.** a slight shock at 8.5.0. A. M. or P. M.

—— 185 (Map 79) ——

March 31.

TOKIO. *Yamato Yashiki* 3.19.53 P. M. NNW 10′. Duration 9″.

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YOKOHAMA. A pendulum seismograph indicated motion which was chiefly E and W.

—— 186 ——

1882. April 1.

27. 10.40 P. M. SW.

—— 187 (Map 37) ——

April 2nd 4.48.51 P. M.

TOKIO. *Yama Guchi.* At 4.48.54 or 4.47.50 P. M. a moderate shock. From the movement of a lamp and the motion of liquids in bottles, the direction was about NE to SW.

There was a slight motion 5 minutes before this.

A pendulum seismograph (Fig. 63) indicated motion in various directions with an amplitude of .5^{mm}.

A rolling sphere (Fig. 64.) on the flat ground at Shinbashi indicated a motion E 22 N of nearly 3^{mm}.

A bracket seismograph (Fig. 65) gave a diagram extending over 40 sec. The period was .33 sec. The EW motion is the more pronounced?

Yamato Yashiki 4.48.51 P. M. ENE, 2°.40′, NNE, 2°, NNW, 1°.10′ Duration 44″.

CHIBA. A slight shock at 4.49.15 P.M. lasting about 20 sec.

A pendulum seismograph indicated 1^{mm} of motion ENE, or ESE.

KUMAGAI. A severe shock at 4.48.45 lasting about 45 seconds.

This earthquake was also felt at:—

5. 4.48 P. M.—**9.** 4.50 P. M.—**12.** 4.45.—**13.** 4.55 P. M. feeble.—**15.** 4.55 P. M. duration 3′.—**27.** 4.00.

—— 188 ——

April 3.

27. 7.00 P. M.

—— 189 ——

April 4.

TOKIO 6.34.47.

A pendulum seismograph indicated motion of .5^{mm} E and W.

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—— 190 ——

1882. April 6.

6. 7.20 A. M.

—— 191 (Map 55) ——

April 8.

TOKIO. *Shinbashi.* A rolling sphere seismograph (Fig. 66) gave a decided motion of 1.2^{mm}.

TOKIO. *Yama Guchi.* At 5.17.1 A. M. a slight shock. There appears to have been a previous shock at 2.41.33.

Yamato Yashiki at 5.12.37 A. M. ESE, 20′.

This earthquake was also felt at:—

8. 5.30 A. M.—**17.** 5.0 A. M. feeble, duration 5^s.—**21.** 5.00 ?

—— 192 ——

April 8.

TOKIO 3.21.00

—— 193 (Map 36) ——

April 9. 3.19.27 P. M.

TOKIO. *Yama Guchi.* By watch at 3.19.21.

By clock at 3.19.20. This is a good example of the accuracy which can be obtained by drawing a watch out of the pocket as compared with an automatic record. The disturbance was slight, lasting about 33 sec.

Yamato Yashiki at 3.19.27 P. M. ENE, 20′, NNW, 20′, NNE, 10′, ESE, 10′, Duration $1^m.48^s$.

This earthquake was also felt at,—

6. 3.00 P. M.—**8.** 3.50 P. M.—**9.** 3.50 P. M.—**10.** 3.00 P. M. feeble.—**13.** 3.23 P. M. feeble, short.—**15.** 3.30 P. M. duration 2^s.—**18.** 3.50 P. M.—**29.** 2.00 P. M. strong. W.

—— 194 ——

April 12.

33. 6.10 P. M. feeble.

—— 195 ——

April 12.

33. 11.40 P. M. feeble.

—— 196 ——

April 13.

19. 6.30 A. M. two shocks.

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—— 197 ——

1882. April 14.

21. 7.00 A. M.

—— 198 ——

April 15.

9. 8.40 P. M.

—— 199 ——

April 18.

5. 7.30 P. M. feeble.

—— 200 (Map 64) ——

April 25.8.23.30 P. M.

TOKIO. *Yamato Yashiki.* 8.33.30? P. M. NNW, 10′.

CHIBA. A slight shock at 8.29.0 lasting 5 sec.

This earthquake was also felt at:—

8. 8.50 P. M.—**9.** 8.40.

—— 201 ——

April 29.

5. 9.05 P. M. rarther strong.

—— 202 (Map 68) ——

April 30. 11.30.0 P. M.

CHIBA. At 11.3.43 P. M. lasting 10 sec.

8. 11.30 P. M.

—— 203 ——

May 1.

5. 1.58 A. M. very feeble.

—— 204 (Map 96) ——

May 2.

TOKIO 5.21.00 P. M.

1. 5.18 P. M. feeble.

—— 205 ——

May 3.

TOKIO 10.58.27

—— 206 ——

May 5.

41. 9.17.9 A.M. duration 3″. sharp shock.

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—— 207 ——

1882. May 9.

9. 6.40 P. M.

—— 208 ——

May 17.

TOKIO 6.50.40 P. M.

—— 209 ——

May 22.

17. 10.20 A. M. long.

—— 210 (Map 26) ——

May 27.

26. 6.20 A. M. feeble.—**29.** 5.40, feeble. W.

—— 211 (Map 27) ——

June 6.

26. 11.25 A. M. feeble.—**27.** 11.15 NE pretty strong.—**29.** 10.50 very strong.

—— 212 ——

June 6.

HAKODATE or **41.** A sharp shock at 6.28. 50 P. M. (local time) lasting about 50 sec. Another observer says it was very slight.

—— 213 (Map 48) ——

June 7.

TOKIO. *Yama Guchi.* A pendulum seismograph showed a motion of .5^{mm} N and S.

Yamato Yashiki 2.26.41 P. M. NNW, 40′, ENE, 20′. ESE, 20′. Duration 19^{s}.

This earthquake was also felt at:—

4. 2.30 P. M. feeble.—**7.** 2.40 P. M. feeble. W.—**8.** 2.30 P. M.—**10.** 2.40 P. M. pretty strong.—**12.** 2.33 P. M. pretty strong.—**14.** 2.16 P. M.

—— 214 ——

June 7.

TOKIO. *Yama Guchi.* A slight shock at 4.25.40 P. M.

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—— 215 ——

1882. June 9.

9. 9.45 P. M.

—— 216 (Map 69).——

June 11.

5. 8.30 A. M. feeble.—**8.** 9.00 A. M.

—— 217 a ——

June 11.

HAKODATE or **41** At 6.55.0 P. M, (local time) a slight shock.

—— 217 b ——

June 13.

HAKODATE or **41.** 6.26.0 A. M. slight.

—— 218 (Map 46) ——

June 14.

TOKIO. *Yamato Yashiki* 10.05.38 P. M. NNW, 20′, NNE, 10′. Duration 40″.

This earthquake was also felt at:—

2. 10.25 P. M. feeble, duration 10″.—**4.** 10.20 P. M. feeble.—**10.** 10.20 P. M. feeble.—**20.** 10.0 P. M. feeble.

—— 219 ——

June 15.

20. 0.58 A. M. feeble.

—— 220 ——

June 16.

41. 6.24.54. Duration 50″. sharp.

—— 221 ——

June 25. **34.** 1.10 A. M. S.

—— 222 ——

July 4.

35. 12.00 P. M. pretty strong. SW.

—— 223 (Map 95) ——

July 10.

TOKIO 11.24.00 P. M.

2. 11.20 P. M. feeble, duration 30″.—**12.** 10.20?

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—— 224 ——

1882. July 13.

34. 11.45 A. M. NW.

—— 225 ——

July 15.

27. 4.01 A. M. S.

—— 226 (Map 107) ——

July 16.

7. 11.30 P.M. feeble SE.—**12.** 10.20 P.M. feeble.

—— 227 (Map 102) ——

July 25.

TOKIO. *Yama Guchi.* A bracket seismograph showed an extremely slight E W motion with a period of .2 sec.

Yamato Yashiki. 1.14.00. P. M. NNE, 50′.

This earthquake was also felt at:—

4. 1.05 P. M. feeble.—**12.** 1.15 P.M. feeble.

—— 228 ——

July 26.

19. 11.45 P.M. pretty strong.—**34.** 11.35 P. M. feeble.

—— 229 ——

July 27.

19. 10.00 P. M. pretty strong.

—— 230 ——

July 30.

2. 11.30 A. M. Duration 10′.

—— 231 ——

Aug. 2.

1. 9.0 A. M. feeble.

—— 232 ——

Aug. 9.

21. 10.25 A. M.

—— 233 ——

Aug. 12.

34. 2.25 A. M.

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—— 234 ——

1882. Aug. 14.

33. 9.30 A. M. W.

—— 235 (Map 35) ——

Aug. 18.

TOKIO 5.34.20 P. M.

Dai Gaku. Prof. Ewing recorded the motion as principally E and W. There is considerable variation in the period of the waves. The largest displacement was about 4.25^{mm}.

This earthquake was also felt at:—

1. 5.30 P. M. feeble.—**2.** 6.00 P. M. feeble, duration 15^{s}.—**4.** 5.23 P. M. pretty strong.—**5.** 5.30 P. M. very strong.—**8.** 5.0 P. M. very strong.—**10.** 5.20 P. M. pretty strong.—**13.** 5.40 P. M. pretty strong.—**20.** 4.35 P. M. feeble.—**26.** 5.30 pretty strong.—**30.** 6.0 feeble, SW.

—— 236 ——

Aug. 22.

38. 9.35 A. M. feeble.

—— 237 (Map 9) ——

Sept. 5.

33. 12. P. M. N.—**35.** 11.20 P. M. feeble.

—— 238 (Map 70) ——

Sept. 11.

4. 4.27 A. M. feeble.—**5.** 4.09 A. M. feeble.—**8.** 5.0 A. M.

—— 240 ——

Sept. 14.

10. 1.30 A. M. feeble.

—— 239 ——

Sept. 14.

4. 0.25 A. M. feeble.

—— 241 (Map 106) ——

Sept. 18.

9. 10.55 A. M.—**10.** 11.00 A. M. feeble.

—— 242 ——

Sept. 19.

8. 2.00 P. M.

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—— 243 (Map 61) ——

1882. Sept. 29.

TOKIO. 5.17.33 A. M. NNW, 1°.20. Duration about 1^m.

Dai Gaku. Prof. Ewing's seismograph chiefly indicated E and W motion. Short period vibrations preceeded the principal movement. The earthquake dies out with waves of a long period.

This shock was very severe at Atami. Grave stones were rotated and projected. There were other shocks at 9 A. M. and 12 o'clock. (For full account see Trans. SS. Vol. V. p. 95.)

This Earthquake was also felt at:—

1. 5.40 A. M. rather strong.—**2.** 5.30 A. M. feeble, duration 40^s.—**3.** 5.30 A. M.—**4.** 5.0 A. M. feeble.—**13.** 5.25 A. M. feeble.—**15.** 5.30. NE, duration 2^s.—**16.** 5.0 A. M. duration 3^s, feeble.—**19.** very strong, in morning.—**21.** 5.30 A. M.—**22.** 5.0 A. M. severe, E.—**23.** 5.40 A. M. SW, severe. (Colour on map ought not to extend to **17.** and **38.**)

—— 244 ——

Oct. 1.

SAPORO or **42.** 7.10 A. M.

—— 245 ——

Oct. 2. Atami about 2 A. M.

3. 1.30 A. M. feeble.

—— 246 ——

Oct. 4.

33. 5.00 A. M. feeble, W.

—— 247 (Map 54) ——

Oct. 4.

TOKIO. *Yamato Yashiki.* 10.48.00 A. M. NNW, 1°.30′, NNE, 10′, ESE, 10′. Duration 14^s.

ATAMI at 10 A. M. on Oct. 5th?

3. 10.30 A. M. feeble.—**15.** 11.45 A. M. E. duration 3^s.—**16.** 11.13. N. duration 3^s.—**17.** 11.10, two shocks, severe.

—— 248 (Map 30) ——

Oct. 6.

8. 11.00 P. M.—**9.** 10.30 P. M.

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—— 249 ——

1882. Oct. 7.

8. 4.00 A. M.

—— 250 ——

Oct. 8.

2. 10.00 P. M. feeble, duration 20ˢ.

—— 251 (Map 78) ——

Oct. 9.

Tokio 5.45.43 A. M. NNW, 30′.

3. 5.30 A. M.—**4.** 5.35 feeble, and 5.47. A. M.—**5.** 5.25 and 5.50 A. M. feeble.—**8.** 5.30 A. M.

—— 252 ——

Oct. 11.

33. 2.00 A. M. W.

—— 253 ——

Oct. 14.

8. 9.30 P. M.

—— 254 (Map 104) ——

Oct. 20.

Tokio. 3.10.37 A. M. NNW, 3°.40′.

2. 3.40 A. M. duration 1ᵐ.—**4.** 3.19 A. M. severe.—**13.** 3.10 A. M. feeble.—**14.** 3.30 A. M.—**15.** 3.30 A. M., E. duration 4,.—**16.** 3.30 A. M. duration 10ˢ.

—— 255 ——

Oct. 20.

8. 5.0 A. M.

—— 256 ——

Oct. 20.

6. 12 P. M. feeble.

—— 257 ——

Oct. 25.

Tokio 6.55.00

—— 258 ——

Oct. 28.

6. 1.00 P. M.

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—— 259 ——

1882. Nov. 5.

33. 6.30 A. M.

—— 260 (Map 58) ——

Nov. 5.

Tokio 10.45.34 A. M. duration 24s.

13. 10.57 A. M. feeble and short.—**15.** 10.30 A. M. SE. duration 3s.—**17.** 11.11 A. M. two shocks very strong, E.

—— 261 ——

Nov. 5.

8. 1.0 P. M.

—— 262 ——

Nov. 8.

26. 11.50 P. M. pretty strong.

—— 263 (Map 73) ——

Nov. 10.

8. 6.15 A. M.—**9.** 7.50 A. M.—**10.** 6.10 A. M. feeble.

—— 264 (Map 11) ——

Nov. 11.

32. 8.35, feeble, not long.—**33.** 8.30 S.

—— 265 ——

Nov. 11.

9. 9.18 P. M.

—— 266 ——

Nov. 11.

36. 10.5 P. M.

—— 267 ——

Nov. 16.

8. 7.00 P. M.

—— 268 ——

Nov. 18.

5. 8.27 A. M. feeble.

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—— 268 b ——

1882. Nov. 19.

HAKODATE or **41.** 7.15.0 A. M. slight.

—— 269 (Map 56) ——

Nov. 21.

17. 1.28 P. M. two shocks.—**20.** 0.40 P. M. feeble.—**23.** 2.0 P. M. feeble, SW.

—— 270 ——

Nov. 22.

32. 10.44 P. M. feeble.

—— 271 ——

Nov. 26.

8. 8.0 P. M.

—— 272 ——

Dec. 2.

33. 7.0 A. M. W.

—— 273 ——

Dec. 3.

31. 4.40 A. M.

—— 274 (Map 22) ——

Dec. 6.

8. 11.40 A. M. pretty strong.—**26.** 11.45 A. M. pretty strong.—**32.** 11.19 A. M. pretty strong and long.

—— 275 (Map 112) ——

Dec. 14.

8. 8.0 A. M.—**20.** 7.10 A. M. feeble.

—— 276 (Map 23) ——

Dec. 23.

9. 11.45 A. M.—**32.** 11.25 A. M. pretty strong and long.

—— 276 b ——

Dec. 26. HAKODATE or **41.** 11.45 P. M. slight.

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—— 277 (Map 21) ——

1882. Dec. 27.

9. 7.0 P. M.—**26.** 6.30 P. M. feeble.—**32.** 6.57, feeble, short. **33.** 7.10 P. M. strong W.

—— 278 ——

1883. Jan. 1.

41. 4.45.0 P. M. (local), duration 25ˢ, slight.

—— 279 (Map 114) ——

Jan. 3.

4. 5.10 A. M. pretty strong.—**15.** 5.10 A. M. duration 3ˢ. E.

—— 280 ——

Jan 3.

SAPORO or **42.** 3.53.30 P. M. (meantime) duration 5ˢ.

—— 281 ——

Jan. 4.

9. 5.23 A. M.

—— 282 ——

Jan. 5.

16. 10.45 P. M. feeble.

—— 283 ——

Jan. 7.

9. 10.0 A. M.

—— 284 ——

Jan. 7.

8. 7.0 P. M.

—— 285 ——

Jan. 10.

26. 3.0 P. M.

—— 286 ——

Jan. 10.

4. 6.30 P. M. feeble.

—— 287 ——

Jan. 10.

8. 8.0 P. M.

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—— 288 ——

1883. Jan. 10.

26. 11.30 P. M.

—— 289 ——

Jan. 11.

33. 2.0 A. M. feeble. S. W.

—— 290 (Map 81) ——

Jan. 11.

2. 6.0 A. M. duration 20ˢ, feeble.—**5.** 7.2 A. M. feeble.

—— 291 ——

Jan. 11.

2. 12.0 P. M. feeble, duration 25ˢ.

—— 292 (Map 71) ——

Jan. 12.

4. 2.0 A. M. feeble.—**9.** 1.4 A. M.

—— 293 (Map 47) ——

Jan. 12.

Tokio. 2.43.53 P. M. duration 20ˢ.

4. 2.18 P. M. pretty strong.—**8.** 2.0 P. M.—**9.** 2.20 P. M.—**10.** 2.5 P. M. feeble.—**14.** 2.20 P. M.—**16.** 2.30 P. M.—**20.** 2.26 P. M. feeble.

—— 284 ——

Jan. 12.

16. 9.15 P. M.

—— 295 ——

Jan. 13.

26. 12 P. M. feeble.

—— 296 (Map. 20) ——

Jan. 14.

9. 2.8 A. M.—**32.** 2.20 A. M. feeble, long.—**33.** 1.28, strong, N. W.—**35.** 2.20 A. M. strong N. W.

—— 297 ——

Jan. 14.

Tokio. 3.42.50 P. M.

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—— 298 (Map 44) ——

1883. Jan. 14.

TOKIO. *Chirikioku.* 4.40.5 A. M. E, 12°.10′, NW, 10°.50′, S W, 6.50, N, 5.30. Duration 40ˢ.

CHIBA. 4.37.7 A. M. duration 45ˢ.

1. 4.50 A. M. pretty strong.—**2.** 5.30 A. M. feeble, duration 57ˢ.—**3.** 4.20 A. M. duration 20ˢ.—**4.** 4.30 A. M. strong.—**9.** 5.0 A. M.—**10.** 4.50 A. M. pretty strong.—**13.** 4.50 A. M. feeble not long.—**14.** 3.30 A. M.—**15.** 4.30 A. M. W. duration 5ˢ.—**16.** 4.30 A. M.—**20.** 4.45 A. M. feeble.—**21.** 4.30 A. M.—**26.** 3.0 A. M. very feeble.

—— 299 ——

Jan. 18.

9. 7.56 P. M.

—— 300 (Map 73) ——

Jan. 19.

8. 7.0 A. M.—**9.** 8.10 A. M.—**10.** 8.22 A. M. feeble.

—— 301 (Map 41) ——

Jan. 22.

TOKIO. 0.20.0 A.M. NW, 6°, SW, 5°.10′. N, 2°.50′, E 10′

CHIBA. 12.20.47, duration 20ˢ, rather severe.

1. 0.15 A. M. feeble, not long.—**2.** 0.20 and 0.30 A. M. both feeble, duration of first 18ˢ and of second 1ᵐ. 9ˢ.—**3.** 12 P. M.—**4.** 0.25 A. M. strong.—**5.** 0.30 A. M. pretty strong.—**8.** 12. P. M.—**9.** 0.20 A. M.—**10.** 11.50 P. M. strong.—**13.** 0.45 A. M. strong not long.—**14.** 0.30 A. M.—**15.** 0.30 A. M. duration 20ˢ. E.—**16.** 11.30 P. M.—**19.** 11.30 P. M.—**20.** 0.20, feeble.—**21.** 0.25 A. M.—**26.** 0.20 strong.—**31** 0.40 A. M.—**32.** 0.23, strong, duration 1ᵐ.—**35.** 0.30. strong N. (The map requires colour up to **35.**)

—— 302 ——

Jan. 22.

26. 1.30 A. M. feeble.

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—— 303 ——

1883. Jan. 22.

26. 2.50 A. M.

—— 304 ——

Jan. 22.

20. 4.0 A. M.

—— 305 ——

Jan. 22.

26. 9.30 P. M. very feeble.

—— 306 (Map 84) ——

Jan. 22.

1. 11.30 P. M. feeble.—**2.** 11.50 P. M. feeble, duration 13ˢ—**3.** 11.40 P. M.

—— 307 (Map 7) ——

Jan. 23.

41. 4.41.4 P. M. duration 25ˢ, slight.

Saporo or **42.** 4.34.30 M. P. (mean time), duration 5ˢ. Not so strong as in Hakodate.

—— 308 ——

Jan. 24.

8. 12.0 P. M.

—— 309 (Map 25) ——

Jan. 25.

9. 5.10 A. M.—**26.** 4.0 A. M. feeble.

—— 310 ——

Jan. 26.

9. 8.25 A. M.

—— 311 ——

Jan. 27.

9. 6.58 P. M.

—— 312 (Map 60) ——

Jan. 31.

Tokio. *Kobu dai gakko.* About 12.15 P.M. This was a long slow earthquake. A lamp was observed to wobble but

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did not swing. This was succeeded at 12.50 by a second similar movement. The 12.15 shock was felt in Tsukiji.

Chirikioku. 0.17.0 P.M. NE, 4°, NW, 3°.10, E, 3°. N, 30′.

This earthquake was also felt at:—

2. 0.30 P. M. pretty strong, duration 18ˢ.—**4.** 0.20 P. M. strong.—**8.** 0.50 P. M.—**9.** 0.10 and 0.45 P. M.—**10** 0.35 P. M. pretty strong.—**13.** 1.0 P. M. feeble.—**14.** 0.28 P. M.—**17.** 11.20 A. M. feeble.—**20** 0.20 P. M. feeble.

—— 313 (Map 51) ——

1883. Jan. 31.

Tokio. *Kobu dai gakko.* At 1.10 P. M. my lecture was almost stopped by the rattling of the windows caused by a sharp earthquake. In the next room the movement was equally severe, but in the chemical lecture room which is in a block of buildings at right angles to where I was, the movement was not observed. About 1.30 P. M. there was another slight shock altogether making four shocks in an hour and a half (see 312.) The 1.10 shock was felt in Tsukiji.

Chirikioku. 1.9.14 P. M. NW, 4°, N, 2.50, E, 1.40, NE, 30. Duration 13ˢ.

Chiba. 1.8.48 P. M. Duration 20ˢ., slight but long.

Kumagai. 1.0.40 P. M. Duration 30ˢ, severe.

This earthquake was also felt at:—

4.—1.15 P. M. strong.—**8.** 1.20 and 1.40 P. M.—**9.** 1.15 and 1.45.—**10.** 1.8 and 1.30, the first being feeble and the second strong.—**13.** 1.30 and 11.50 P. M. the first feeble and the second pretty strong.—**14.** 1.5 and 1.24 P. M.—**16.** 1.20 P. M. duration 15ˢ.—**17.** 1.10 P. M. strong, duration 2ᵐ.—**20.** 1.16 feeble.—**26.** 1.30 P. M. feeble.

—— 314 ——

Feb. 2.

41. 1.54 P. M (local). Duration 1ᵐ.40ˢ.
A succession of slight shocks.

—— 315 ——

Feb. 3.

26. 3.30 A. M.

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—— 316 ——

1883. Feb. 3.

26. 11.50 A. M.

—— 317 ——

Feb. 3.

8. 5.30 P. M.

—— 318 ——

Feb. 4.

9. 3.59 A. M.

—— 319 ——

Feb. 4.

33. 9.0 A. M. feeble.

—— 320 ——

Feb. 6.

35. 4.50 P. M. feeble. N.

—— 321 ——

Feb. 7.

20. 0.45 P. M.

—— 322 ——

Feb. 9.

35. 4.10 A. M. pretty strong and long.
36. 4.35 A. M. pretty strong.

—— 323 ——

Feb. 9.

9. 12.0 P. M.

—— 324 ——

Feb. 14.

9. 9.35 P. M.

—— 325 (Map 8) ——

Feb. 15.

32. 10.0 P. M. strong and long.—**33.** 9.24 P. M. N. W.

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—— 326 (Map 71) ——

1883. Feb. 16.

4. 10.45 P. M. feeble.—**9.** 8.30 and 10.0 P. M.

—— 327 ——

Feb. 21.

9. 1.50 A. M.

—— 328 ——

Feb. 21.

2. 3.22 A. M. pretty strong, duration 16ˢ.

—— 328 b ——

Feb. 26. SAPORO or **42.** 11.20 A. M.

—— 329 ——

Feb. 27.

20. 12.0 P. M. feeble.

—— 330 ——

Feb. 28.

41. 1.50.4 P. M. duration 1ᵐ.40ˢ, slight. A series of slight shocks. Also at Saporo, slight.

—— 331 ——

March 3 or 5.

41. 10.38.29 or 10.42.25 A. M. (local) duration 1ᵐ.30ˢ very slight. Two shocks.

—— 332 ——

March 4.

5. 2.30 P. M. very feeble.

—— 333 (Map 77) ——

March 9.

TOKIO. *Chirikioku.* 10.28.0 A. M. E 1°.10′. NW 20′—**20.** 10.25 A.M. feeble.

—— 334 ——

March 14.

TOKIO. *Chirikioku.* 4.35.38 A. M. NE 1°.0′, N 30′, E. 20′. Duration 8ˢ.

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—— 335 (Map 80) ——

1883. March 15.

TOKIO. *Chirikioku.* 7.57.02 A.M. NE 50′.

2. 8.0 A. M. pretty strong, duration 53ˢ.—**4.** 8.5 A. M. feeble.—**20.** 8.0 feeble.

CHIBA 7.55.34 P. M. very slight.

—— 336 ——

March 29.

8. 6.30 P. M.

—— 337 ——

April 3.

26. 3.50 A. M.

—— 338 ——

April 3.

33. 5 A. M. feeble. W.

—— 339 ——

April 6.

33. 6.4 A. M.

—— 340 ——

April 7.

41. 1.5 P. M. duration 50ˢ, small.

—— 341 ——

April 18.

YOKOHAMA 8.42.40 A. M., slight.

—— 342 ——

April 19.

YOKOHAMA 5.10 A. M. slight.

—— 343 ——

April 20.

HAKODATE. 3 A. M. N. S. strong and again at 4.43 A. M.

SAPORO. strong, also a second shock.

—— 344 (Map 103) ——

April 20.

TOKIO. *Chirikioku.* 9.57.10. NE 2°, SE 1°.20′, N. 30′. Duration 1ᵐ.

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YOKOHAMA. 9.53. P. M. duration 5ˢ, NS. gentle.

4. 9.55 P. M. feeble.—**14.** 10.10 P. M.

—— 345 (Map 100) ——

1883. April 21.

YOKOHAMA. 9.22.20 A. M. duration 1ˢ. slight. NS.

14. 9.20 A. M.—**20.** 9.16 A. M. feeble.

—— 346 ——

April 23.

33. 6 A. M. W.

—— 347 (Map 52) ——

April 23.

TOKIO. *Kobu dai gakko.* Shock at 10.34.30 P.M. duration 40ˢ, but the bubble of a level was seen to move for 30ˢ the after motion of the ground had ceased. The movement was 1 to 2ᵐᵐ in jerks to the NNW every 2ˢᵉᶜ. There was a second shock at 10.42.10, perceptible by the level 20ˢ.

Dai Gaku. Prof. Ewing recorded the first of these earthquakes as lasting over 4½ᵐ. The greatest motion was 5ᵐᵐ. The greatest vertical motion less than 1ᵐᵐ. The period was about .8 sec. A principal direction of motion was E 30° N.

Chirikioku. 10.32.50 P. M. Directions E. 11°.10′. SW. 10°.10′. N 8°.50′. NW 3°.10′. Duration 1ᵐ.15ˢ. A second shock at 10.41.20.

Chiba. 10.23.58 P. M. Duration 10ˢ. Again at 10.38.13. Duration 45ˢ.

Yokohama. 10.28.50. Duration 50ˢ. Rather severe N.S. Just before the shock, frogs ceased croaking and remained silent for some time afterwards. A second shock at 10.36.50. Duration 25ˢ. N & S, mild.

This shock was also felt at,—

1. 10.50 and 11.0 P. M., both feeble.—**2.** 11.0 and 11.6 P. M. both feeble, durations 1ᵐ.9ˢ and 20ˢ.—**3.** 11.40 P. M. **4.** 10.30 and 10.39 P. M. both feeble.—**10.** 10.10 and 10.40 P. M. first strong and second feeble.—**13.** 10.55 and 11.0,

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P. M. strong.—**14.** 10.50 and 11.0 P. M.—**15.** 11.0 P. M., duration 40ˢ, W.—**16.** 10.28 and 10.35 P. M.—**19.** 8.30 P. M. duration 1ᵐ, strong.—**20.** 10.30 and 10.37, feeble.—**23.** 10.37 and 10.50 feeble, SW.

—— 348 ——

1883. April 24.

10. 5.20 A. M. feeble.

—— 349 ——

April 25.

TOKIO about 7.15 A. M.?

—— 350 ——

April 29.

33. 12.0 P. M. feeble.

—— 351 (Map 94) ——

May 2. TOKIO. *Chirikioku.* 5.17.06 P. M. E 3°30′, SW 2°, NW 1°.50′, N. 1°.30′. Duration 20ˢ.

CHIBA 5.17.13, P. M., duration 17ˢ.

4. 5.15 P. M. feeble.—**20.** 5.55 P. M. feeble.

—— 352 ——

May 2.

33. 7.0 P. M. feeble SW.

—— 353 ——

May 6.

TOKIO. *Chirikioku,* about 6 P. M.

—— 354 ——

May 10.

38. 1.14 P. M. feeble.

—— 355 ——

May 12.

33. 5.20 P. M. S. feeble.

—— 356 ——

May 12.

8. 12.0 P. M.

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—— 357 (Map 62) ——

1883. May 13.

TOKIO *Chirikioku.* 1.18.23 A.M. E 3°.30′, NW 10′, N. 10′. Dogs were heard to howl after this shock.

CHIBA. 1.22.0 A. M. duration 30ˢ. very slight.

4. 1.10 A. M. pretty strong.—**20.** 1.7 A. M. feeble.—**22.** 1.20 A. M., feeble, SE. duration 3ᵐ.

—— 358 ——

May 16.

38. 6.43 A. M. feeble.

—— 359 (Map 6) ——

May 18.

33. 7.50 A. M. feeble, S.—**35.** 7.55 A. M. feeble, N.—**41.** 7.18.37, slight and short.

—— 360 (Map 98) ——

May 23.

TOKIO. *Chirikioku.* 5.58.52. E 1°.20′, NW 1°.10′. N 1°. SW 30′. Duration about 1ᵐ.

I was walking about in the garden at the time and did not feel it. An inspection of the map shows that the long axis of the area over which this shock was felt, corresponds with the principal direction of motion as observed in Tokio.

2. 6.4 P. M. pretty strong, duration 53ˢ.—**3.** 5.55 P. M. **4.** 5.48 P. M. feeble.—**8.** 6.0 P. M.—**13.** 6.0 P. M. feeble.

—— 361 ——

May 24.

41. 3.51.4. Two shocks, the first short, the second 30ˢ.

—— 362 ——

May 24.

8. 7.0 P. M.

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—— 363 (Map 56) ——

1883. May 28.

TOKIO. *Chirikioku* 1.15.10.

15. 1.20 P. M., duration 10ˢ. E.—**17.** 1.20 P. M. two shocks, strong.—**20.** 1.10 P. M. feeble.—**23.** 1.15 P. M. pretty strong, SW.

In *Yokohama* Mr. Talbot in his garden did not feel the motion but distinctly saw a large motion in his house.

—— 364 (Map 67)

May 29.

TOKIO. *Chirikioku* 6.07.02 E. 1° 50′, NW 1°.50′, SW 40′, N 10′. Duration 21ˢ.

CHIBA. 6.5.14 P. M., duration 45ˢ, slight.

4. 5.57 P. M. feeble. **8.** 5.0 P. M.

—— 365 ——

June 9.

8. 7.0 A. M.

—— 366 ——

June 9.

33. 6.0 P. M. feeble, SW.

—— 367 (Map 43) ——

June 10.

TOKIO. *Chirikioku*, 10.15.0 P. M. N 18° 20′, NW 14° 10′, E 11° 10′. NE 11.°0′. Duration 1ᵐ 10ˢ

YOKOHAMA. 10.8.20. Duration 1ᵐ 20ˢ. NS. very severe.

CHIBA. 10.12.53. Duration 2ᵐ 15ˢ. Severe.

This earthquake was also felt at;—

1. 10.30 P. M. pretty strong.—**2.** 10.50 P. M. pretty strong, duration 2ᵐ 30ˢ.—**4.** 10.10 P. M., strong.—**5.** 10.40 P. M., pretty strong.—**8.** 10.0 P. M.—**13.** 10.10 P. M. strong. —**16.** 10.5 P. M.—**20.** 10.10 P. M., feeble.—**21.** 10.0 P.M. —**23.** 10.10 P. M. feeble.

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—— 367 b ——

1883. June 11.

SAPORO or **42.** 5.30 A. M.

—— 368 (Map 97) ——

June 12.

TOKIO. About 6.13.0 P. M.

2. 6.0 P. M., pretty strong, duration 1^m 50^s.—**4.** 5.55 P. M. pretty strong.—**5.** 6.25 P. M., feeble.

—— 368 b ——

June 24.

HAKODATE or **41.** 3.54 P. M.

—— 369 ——

June

CHIBA. 2.55.2 A. M. duration 3^s.

—— 370 ——

June 19.

4. 10.10 P. M. feeble.

—— 370 b ——

June 24.

SAPPORO or **42.** 3.53.48 P. M. EW.

—— 370 c ——

July 4.

HAKODATE or **41.** 3.07 P. M. also at Sapporo.

—— 371 (Map 99) ——

July 13.

TOKIO. 3.44.00 about.

8. 5.0 P. M.—**14.** 4.0 P. M.

The colour on the map does not extend sufficiently far towards the South.

—— 372 ——

July 13.

8. 11.0 P. M.

—— 373 ——

July 16.

8. 7.0 A. M.

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— 374 —

1883. July 18.

33. 7.0 P. M. W.

— 375 —

July 18.

Tokio. About 8.50.00 P. M.

— 376 —

July 19.

33. 6.0 A. M., feeble, W.

— 377 —

July 27.

16. 5.7 P. M.

— 378 (Map 67) —

July 27.

4. 7.40 P. M., feeble.—**8.** 7.30 P. M.

— 379 —

July 27.

Tokio. About 2.25 A. M.

— 380 —

July 29.

33. 3.20 and 4.6 P. M. feeble S.

— 381 —

Aug. 2.

41. 5.36.4 A. M., sharp.

— 381 b —

Aug. 9.

Saporo or **42.** 11.07 P. M.

— 382 —

Aug. 6.

4. 11.59 P. M., feeble.

— 383 —

Aug. 17.

Tokio. 2.38.41 P. M. Duration 24s.

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—— 384 ——

1883. Aug. 30.

38. 2.20 P. M., feeble.

—— 385 ——

Sept. 13.

38. 0.15 A. M., feeble.

—— 386 ——

Sept. 15.

5. 7.30 P. M., feeble.

—— 387 (Map 69)——

Sept. 23.

5. 6.30 A. M.—**8.** 7.20 A. M.

III. GENERAL RESULTS.

1. *Distribution in Space.*

The number of shakings which have been felt at different places in north Japan are given in the right hand column of table I. The numbers in the left hand column of this table denote towns at which observations were made. It will be seen that the greatest number of earthquakes were felt at number 8 (Asaw) where 82 distinct shocks were recorded. Other places situated near to number 8, like 9,10 and 4 (Mito, Shimodate and Sakura) also record a high number of disturbances.

Many shocks have been quite local in their character not having been sensible over an area greater than 50 square miles.

From an inspection of the table II in which these local shocks are indicated, it appears that there have been 198 local shocks on the seabord and 56 inland, or a total of 254 local shocks out of the 387 which have been recorded. Some of the local shocks observed at places on the coast may have extended over an area greater than 50 square miles.

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Places.
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45
46
Total.

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TABLE II.

On the coast		Inland	
Number of Place	Number of Shocks	Number of Place	Number of Shocks
Tokio	17	22	2
Yokohama	2	16	3
19	5	10	8
25	9	12	4
21	2	7	1
20	3	14	1
2	14	29	5
3	2	40	5
9	13	42	5
8	22	35	4
5	7	34	8
6	6	38	5
4	8	17	2
26	16	31	2
27	3	30	1
32	1	Total.	56
39	3		
36	3		
33	19		
41	15		
44	17		
46	1		
Total.	198		

The high number of local shocks recorded for Tokio. may be due to their having been many observers and instruments in that city, the latter indicating shocks which otherwise would have been passed by unnoticed.

The majority of the remaining 133 shocks, extended over a land surface the average diameter of which was about 45 miles. Some four or five shocks created a disturbance over the whole of Yezo and the eastern coast of Nippon as far south as Tokio or Fujisan. The *land* area shaken equalled about 44,000 square miles. The total area shaken had probably a radius of at least 150 miles. These latter shocks originated

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far out at sea and consequently have not been so alarming in their character as many which originated nearer to or beneath the land.

2. *Simultaneous shocks.*

A curious set of disturbances are those which have occurred simultaneously at distant localities whilst intermediate stations have not recorded any disturbances.

Earthquakes number 161 and 165 are examples of these disturbances. Each of these earthquakes was only felt at stations 19, 25, 10 and 34. Both earthquakes occurred on succeeding nights about 11 P. M. That these particular stations which are widely removed from each other should on two succeeding nights have coincided in reporting earthquakes can hardly be regarded as accidental.

A tabular view of these coincidences is as follows.

Number of Earthquake.	Places at which felt.	Number of Map.
161	19, 25, 10, 33.	123
165	19, 25, 10, 33.	122
140	25, 10.	118
153	25, 26.	116
183	Tokio, 36	120
10	Tokio district, 39.	111
97	Tokio district, 26 and 27.	110
83	26, 14.	115
134	Tokio district, 30, 34 and 36.	121
85	Tokio district, 31 and 30.	119
179	2, 9.	117
179	15, 4.	114
87	38, 33 and 34.	113
132	34 and 46.	

From this table it will be seen that it has not been uncommon to have an earthquake at or near Tokio in the south, together with one at some place like 33, 34, 36 or 39 about 200 miles distant up the coast.

It is of course possible that there has not been an exact synchronism in these shocks inasmuch as the exact time at which they occurred is unknown.

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3. *Origins of Earthquakes.*

By reference to the observations which were made on various earthquakes it will be seen that in many instances materials have been collected which are sufficient for the approximate determination of the origins from which many disturbances have radiated.

For example if an earthquake was only felt at station 12, it is assumed that it must have originated near that station. If however an earthquake was felt at a large number of stations, but at one of them it was very severe or was there followed by a series of small shocks, it is assumed that the origin was probably nearer to the one where then had been the greatest seismic activity. In these determinations, instrumental observations on direction and time have also been of great assistance.

The approximate origins which have in this way been determined are indicated by a series of areas marked alphabetically in map No. 124

The areas from A to H are in the ocean, I to N are either on the sea bord or very near to the sea bord, while the remaining areas are inland.

The earthquakes originating about C are those which have been felt over all Yezo and the eastern side of Nipon as far south as Tokio. Those originating in E have only been felt about 26 and 27. In some instances it has been difficult to determine in which of two contiguous areas the origin of a certain earthquake ought to be located. Thus an earthquake considered to have come from the southern end of area D, may perhaps have originated at the northern end of E. Again with certain earthquakes which shook the mouth of the Tonegawa it has been a somewhat arbitrary determination to say whether they originated in T, K or F.

As contiguous areas will be taken together when considering the general distribution of seismic activity, irregularities in determination of origin like those just considered, will not influence the general results.

The number of earthquakes originating in the areas which have been indicated, are shown in the following table.

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They are also shown on the map.

I		II		III	
Origins beneath the Ocean		Origins on or near the Sea bord		Origins inland	
Area.	No. of Shocks	Area.	No. of Shocks	Area.	No. of Shocks
A	17	T	8	O	1
B	17	J	62	P	7
C	6	K	39	Q	3
D	42	L	6	R	10
E	38	M	18	S	35
F	77	N	4	T	2
G	14	—	—	U	6
H	7	—	—	—	—
Total	218	Total	137	Total	64

The general result is that the greater number of earthquakes felt in north Japan have originated beneath the ocean. If we consider I and II as belonging to the same group then we may say that 355 earthquakes out of 419 or *84 per cent have originated beneath the ocean or on the sea bord.*

The district which is the most shaken is the flat alluvial plain of Musashi following the line of the river Tonegawa. This district may include the areas F, J, K and S, from which area 213 earthquakes out of 419 have originated.

The number 387 has become 419 in this table because an earthquake which was simultaneously felt at two distant stations has been reckoned as belonging to two distinct areas.

This area of greatest seismic activity forms one of the flattest parts of Japan. The large number of earthquakes which have been felt on the low ground and the comparatively small number which have been felt in the mountains is certainly remarkable.

It must also be observed that in the immediate vicinity of active or extremely recent volcanoes the seismic activity has been small. An inspection of the map showing the

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general distribution of volcanoes in Japan and the regions of greatest seismic activity indicate that the volcanic and seismic activity are not directly related to each other. If they are connected, we may ask why are earthquakes only frequent on one side of the band of volcanoes which partially surrounds the Musashi plain, whilst amongst the volcanoes and on the opposite side of them from Tokio, earthquakes are comparatively rare? It may also be remarked that the side of Japan on which earthquakes are the most frequent is the side which slopes down steeply beneath an ocean which at 120 miles from the coast has a depth of about 2000 fathoms, whilst on the opposite side of the country at the same distance from the shore the depth is only about 140 fathoms. Another point not to be overlooked is the fact that the district where earthquakes are the most numerous is one where there is abundant evidence of a recent and rapid elevation.

In all these respects the seismic regions of Japan hold a close relationship to similar regions in South America where we have earthquakes originating beneath a deep ocean, at the foot of a steep slope on the upper parts of which there are numerous volcanic vents, whilst on the side of this ridge opposite to the ocean earthquakes are rare. With regard to the Musashi area it may also be remarked that sediments brought down by numerous rivers from the higher parts of the country are accumulating on it at a very rapid rate.

4. *Relation of earthquakes to various Natural Phenomena.*

Almost all seismologists who have compiled lists of earthquakes have by means of tables and curves endeavoured to show the relation between these disturbances and other natural phenomena. Perrey and Mallet amongst other things have shown us that earthquakes are more frequent at the following times.

1°. In relation to the moon. Earthquakes are frequent at the syzgies, when the moon is in perigee and when the moon is near her meridian passage.

2°. In relation to the sun. Earthquakes are more frequent during the winter months.

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These and other laws which have crept into text books of Geology are in the majority of cases founded on extremely slender evidence and we must remember that the exceptions to them are very numerous.

As investigations similar to these have already been made for the earthquakes of Japan, by Messrs Knipping, Naumann and other workers, it is not my intention to repeat them unless they indicate laws more definitely than those which have previously been made.

(a) *Relation of earthquakes to the seasons.*

The number of earthquakes which have been felt in different months and during different seasons is shown in the following table.

	1881	1882	1883	Total	
January	—	40	36	76	195
February	—	44	17	61	
March	—	52	6	58	
April	—	17	14	31	70
May	—	8	14	32	
June	—	11	6	17	
July	—	9	10	19	39
August	—	6	4	10	
September	—	7	3	10	
October	7	15	—	22	83
November	16	13	—	29	
December	26	6	—	32	

Winter months.....278
Summer months 109
Total 387

From this table it appears that the greater number of earthquakes occured during the coldest months that is in January, February and March. Or if we take these months in conjunction with October November and December to represent the winter, the remaining months being the summer, the winter earthquakes were to the summer earthquakes as 278 to 109.

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These results accord with those previously obtained for the Tokio area alone, by observations lasting over a long period of years. The only value of the table just given is that it shows the winter law, more definitely than it has hitherto been represented.

6. *Relation of Seismic Intensity to the Seasons.*

In the last table only the number of earthquakes which have been felt were considered, and the 278 during these winter months might have been exceedingly small disturbances whilst the 109 in summer might have been severe.

Assuming that the observation stations are evenly distributed over the area in which observations have been made, some approximation to the intensity may be obtained by giving a value to each earthquake corresponding to the number of stations at which it was felt. A result like this is given in Table I, from which it will be seen that 737 records were sent in for January February and March, 199 for April May and June, 95 for July August and September and 308 for October November and December. Summing these up, we obtain the number 1045 to represent the winter intensity, and 294 to represent the summer intensity, *that is to say, the winter intensity is nearly three and a half times as great as the summer intensity.*

7. *Frequency of Earthquakes in all Japan.*

For about half of the empire of Japan, in two years, the first being one in which earthquakes were frequent and the other a year when earthquakes were few, 387 shocks were registered without the aid of instruments. Had instruments been employed,—if we may judge from the Tokio district where there were many instruments,—this number would have been considerably increased. For the whole of Japan we may therefore safely assert, that on the average there is at least one earthquake per day. There may possibly be two or three.

This is an estimate which some Seismologists have

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given for the whole world, a deduction based on earthquake calendars published annually in Europe. If the records contained in these calendars are as imperfect for other parts of the world as they are for Japan, we might conclude that in the world generally there are at least 20 earthquakes per day, or perhaps 50.

8. *The occurrence of earthquakes in relation to changes in temperature.*

Hitherto the relation of earthquakes to changes in temperature has only been indicated by means of tables and diagrams showing the relation of earthquakes to the months and seasons.

In the first of the accompanying figures, the dotted line shows the change in the mean monthly temperature at Tokio, whilst the full line indicates the number of earthquakes which have been felt in sucessive months.

The lowest temperatures it will be observed are from December to March, the highest being in July and August. The greatest number of earthquakes have occurred during the former of these two seasons, but it will be noticed that there is a tendency for this period of maximum seismic energy to continue on into April.

This is more definitely shown in the second figure where the relationship of earthquakes recorded in Tokio to mean monthly temperatures, is given for a period of 6 years.

In this table we see a *general coincidence between the maximum of earthquakes and the minimum of temperatures.*

It must however be noted that the sinuses of the temperatures curves are generally a little in advance of the crests of the earthquake waves.

Had the temperature curve been that of the waters surrounding Japan, inasmuch as water increases in temperature slowly and parts with it slowly, the occurrence of earthquakes with the minima temperatures might have been still more marked.

As we have already shown that the majority of the earthquakes felt in Japan originate beneath or near the

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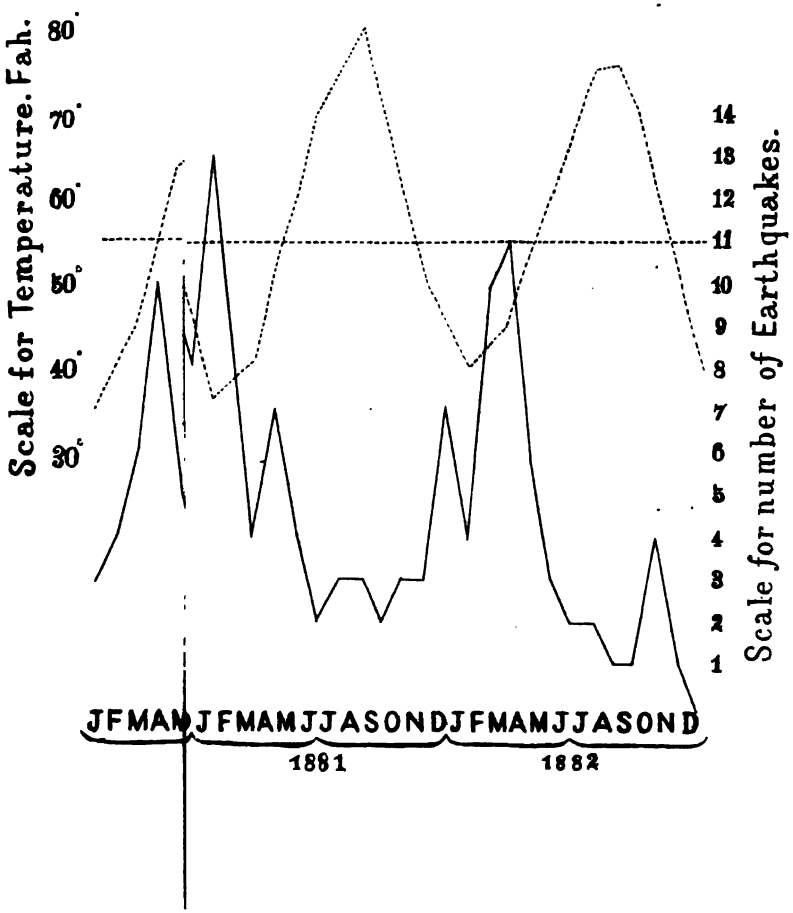
NTHLY TEMPERATURE.



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ocean, this coincidence is significant of a possible connection between the two.

9. *Earthquakes in relation to the relative position of the Moon and Sun:*

The results I obtained show that out of 264 earthquakes,

72	occurred	at	or	within	4	days	of New moon
52	„	„	„	„	„	„	„ First quarter
65	„	„	„	„	„	„	„ Full moon
75	„	„	„	„	„	„	„ Third quarter

Prof. Chaplin found a maximum at quadrature, a result which apparently agrees with an investigation by Mr. E. Knipping.

Speaking generally on this subject, I can not say that any marked coincidence in the occurrence of earthquakes and the phases of the moon have been observed. Although Prof: Perry has found a maximum of earthquakes for the moons perigee, such a maximum has not been found in Japan.

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Origins.	Hours before high water						High water at Tokio	Hours after High water					
	6	5	4	3	2	1	0	1	2	3	4	5	6
A	2	..	1	..	1	1	2	4	2	1	4	..	..
B	3	1	2	2	1	1	2	2	3	2	1	..	..
C	1	..	1	1	..	..	..	..	..	2	1	1	..
N	1	..	..	..	1	1	..	1	..	..	..	..	..
D	7	7	2	2	5	2	4	2	3	4	3	2	..
M	2	1	3	1	3	1	1	3	2	2	..	..	..
E	3	5	5	5	5	6	3	3	2	4	3	3	..
L	1	1	..	1	1	..	..	1	1	..	1	2	..
F	11	10	4	9	10	4	6	12	10	8	4	10	..
K	5	5	2	2	6	5	2	4	7	2	3	5	..
J	6	10	9	4	5	6	8	10	5	3	3	9	..
S	6	2	1	3	5	2	4	4	4	5	2	5	..
R	..	..	1	1	2	..	..	2	1	..	2	3	..
I	2	2	..	1	..	1	2	1	..	1	1	..	..
H	1	2	..	..	..	1	..	2	..	2	..	..	..
G	2	1	1	2	2	1	1	1	2	3	..	..	..
Q	..	..	2	1	..	..	..	1	1	..	..	..	..
P	3	1	..	..	2	1	..	..	..	..	..	1	..
O	..	..	..	..	..	..	..	..	..	..	..	..	..
T	..	1	1	..	..	..	..	1	1	..	..	..	..
U	..	..	1	2	..	1	..	1	2	..	..	..	..
	56	49	36	37	49	34	37	55	46	39	33	41	..
	146		122			126			118				

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10. *Earthquakes and the Tides.*

The foregoing table shows the relation between the occurrence of earthquakes and the state of the tides. Inasmuch as there are inaccuracies in the times at which earthquakes have been observed, it has not been considered necessary to carry the comparison with the state of the tide to within fifteen minutes.

In the accompanying table, *0* indicates one hour at the time of high water at Tokio, that is half an hour before high water and half an hour after high water. The numerals to the right and left of *0*, indicate hours before and after high water at Tokio. The letters A B C &c. denote areas from which shocks have originated. The number of shocks which have originated in these various areas at different hours of the tide are given by numerals horizontally following the letter of the station to which they refer.

Adding up these various columns and grouping them in four periods of approximately three hours each, we see that there has been a slight preponderance of earthquakes at the three hours representing low water. An error tending to obscure this general result, is the want of a correction for the state of the tide in the northern areas like A B C &c. where the tide is from 1 to 1½ hours earlier than in the south. Another error is the inclusion in the list of areas like Q T U which are situated far inland and removed from any direct influence of the tide on the coast.

The best result is seen by taking areas where earthquakes have been the most numerous and for which the time of high water is practically the same in all. Such a group of areas is the group F K S T.

This area shows that at low water there were 84 shocks, at half tide rising 60, at full tide 67, and at half tide falling 61. *Comparing together the low water earthquakes with those which occurred at high water we see that the former are about 11.2 per cent more numerous than the latter.*

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11. *Results relating to Earthquake Motion,*

In the introduction to this paper three important results which have been obtained have already been enumerated. (see p. 5.)

The majority of the earthquakes which have been registered have consisted of a series of irregular vibrations usually lasting over a period of from 20 to 60 seconds. What I should call a complete earthquake is illustrated in Fig. 58. In this diagram we observe that the disturbance consisted of three parts. First there was a series of exceedingly small vibrations having a quick period. Next came a sudden motion of large amplitude constituting the shock of the earthquake, and lastly a long series of motions irregular both in period and amplitude. A marked character in many earthquakes has been that these latter motions died out with a decreasing period.

In the diagram referred to, the preliminary tremors are visible over a period of almost 12 seconds. There appears to have been from 5 to 6 complete vibrations per second. Had the instrument been sensible to waves of a smaller amplitude, it is probable that the duration of the preliminary tremors would have been increased still more. From a consideration of diagrams like this, it is also probable that the actual commencement of a disturbance has never yet been recorded. Might we not therefore ask the question whether this unrecorded portion of an earthquake has not been made known to us by the sound phenomena which often precede large earthquakes? The nearer we are to the commencement of an earthquake the quicker are the vibrations, and we have only to reduce the period of vibrations already recorded, one third, to be within the limit of vibrations sufficiently rapid to produce in the air a disturbance which might be audible.

The amplitude of the shock or shocks which an earthquake may contain, usually varies between 1 and 10 millimeters, the maximum motion in ordinary earthquakes where there is no well defined shock usually being from .1 to 1^{mm}.

In several cases the greatest motion of shock appears to have been inwards or towards the origin of the shock. One

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characteristic of the shock of an earthquake is, that it has a definite direction which may be recorded over a large area, whilst the other motions of an earthquake, in fact all the motions of an ordinary earthquake, are movements which continually change in direction and may be very different even at two neighbouring stations.

In other words we may say, that the direction of vibration of the ground in an ordinary earthquake has usually no immediate relation with its direction of propagation.

The maximum acceleration during these movements of shock may reach as much as 500^{mm} per second per second. Ordinary earthquakes have maximum accelerations of from 10 to 100^{mm} per second per second.(1) A motion like the former is on the verge of being destructive and brick chimneys may be cracked. These calculations are based on the assumption that the motion is like that of an ordinary pendulum. Hitherto the records have been drawn on plates which move too slowly to sufficiently spread out the waves of shock. In consequence of this it has not been possible to make the necessary time measurements enabling us to calculate maximum accelerations without making assumptions as to the nature of the motion. Here and there, where I have attempted to make such calculations, it will be observed that the results obtained are very much lower than any of the results obtained where simple harmonic motion has been assumed.

I may mention that I am now endeavouring to obtain records of earthquakes on rapidly moving plates.

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(1) *The above accelerations are calculated on the assumption that* $a = \frac{V^2}{a}$ *where,* -

a = *maximum acceleration.*
V = *maximum velocity.*
a = *amplitude or half a semioscillation.*

The intensity of an earthquake or its power of overturning and shattering objects may also be represented by the quantily $\frac{V}{t}$, *where,*—

V = *the maximum velocity*
t = *the quarter period.*

The power of projection will be measured by V. These questions are more fully discussed in my next paper to the Society on "Seismic Experiments."

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Prof. Alexander suggested to me that it is not improbable that the portion of an earthquake which I have called the shock, may have been executed so rapidly that the rocks in which this disturbance took place had not time for elastic yielding. There was in fact a sudden "push". The portion of the area thus affected might be called the core of the earthquake. If such a condition as this exists, we have in it a means of explaining the enormously high velocities of propagation which have sometimes been recorded.

Lastly we come to the resulting tremors which are irregular in period in amplitude and in direction. These resulting tremors of a large disturbance are identical in character with the collection of vibrations which constitute an ordinary earthquake. They usually vary in period from .2 to 1 second, but I have noted them with a period of 2 or 3 seconds. These latter waves die out so slowly that they are seldom felt, and if an instrument is not very sensitive they may not be recorded. They may however be seen in the slow oscillations of the bubble of a delicate level long after all sensible motion has ceased. That these motions are not due to the inertia of the liquid in a level, may be easily verified by suddenly tipping a level and it will then be seen how quickly the bubble returns to rest.

The end of an earthquake like its commencement is therefore an indefinite point.

This leads me to consider the duration of an earthquake. Earthquakes in Japan are usually felt over a period of from 20 to 60 seconds, but I have mentioned instances where records have been traced over 4½ minutes. Had the instruments which gave these records had sufficient multiplication to record all the small motions at the commencement of the disturbance, and had they been sufficiently frictionless to record the slow pulse-like motion at the end of disturbance, it is probable that the duration of the earthquakes recorded would have been very much greater than that here given. *Strictly speaking we do not yet know the duration of an earthquake.*

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With regard to the velocity at which an earthquake may be propagated, I have sometimes obtained results indicating this quantity to be several hundreds of feet per second, and sometimes several thousands. It must however be remarked that although the means I have had for these determinations are equally as good as any hitherto employed, they are nevertheless open to so many errors that the results yet obtained must be allowed to stand over for farther confirmation

The general conclusions towards which these results point are as follows:—

1. Different earthquakes have travelled across the same area with different velocities
2. The greater the initial disturbance the greater has been the recorded velocity.
3. The same disturbance spreading from its origin is propagated with a decreasing velocity.

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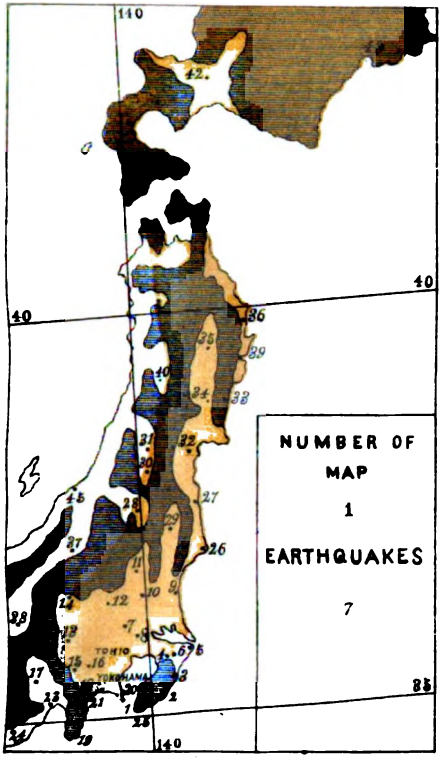

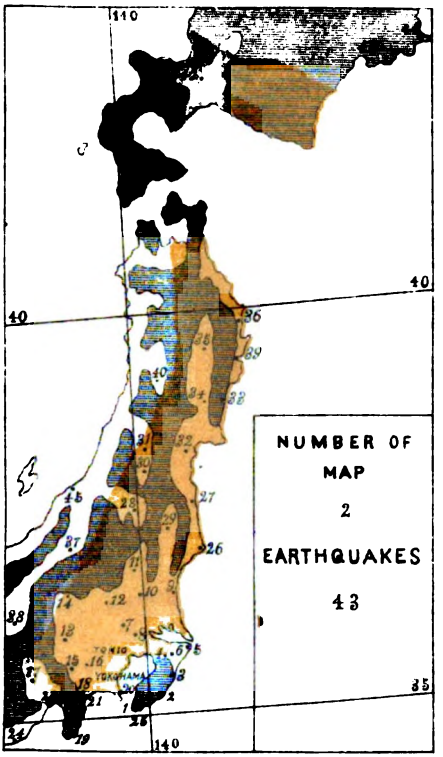

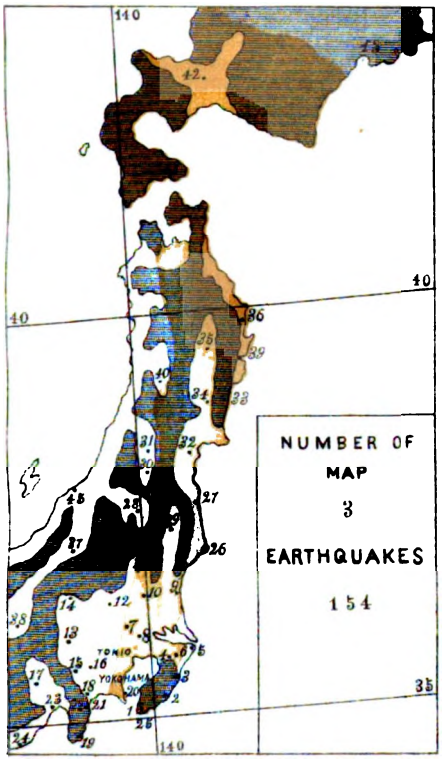

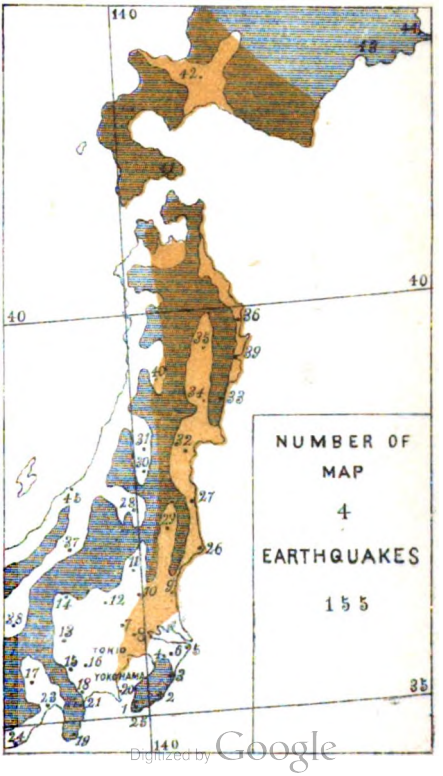

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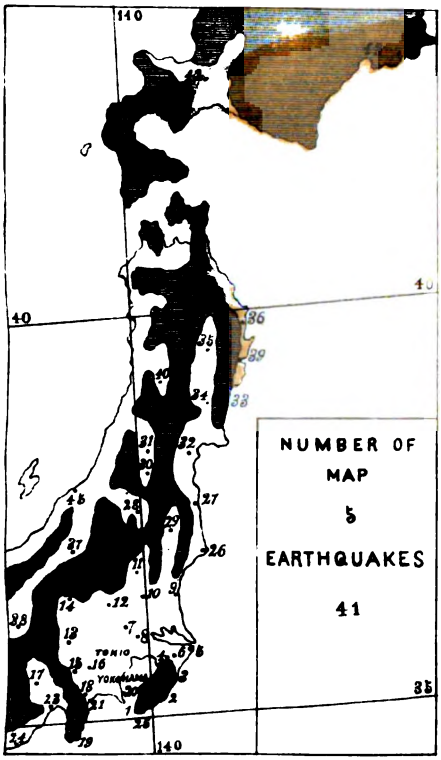

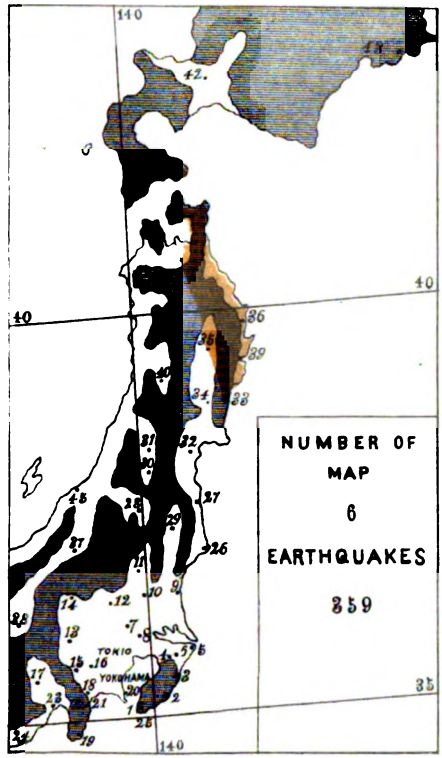

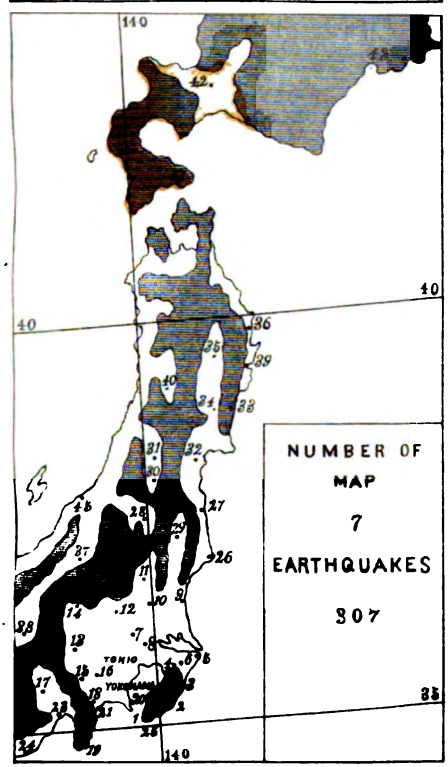

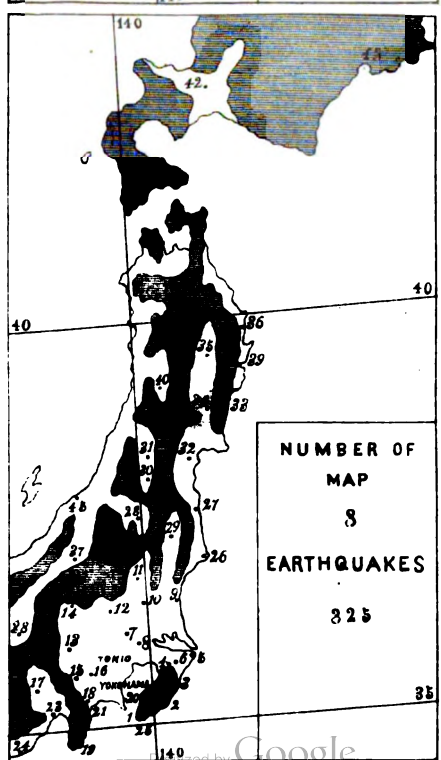

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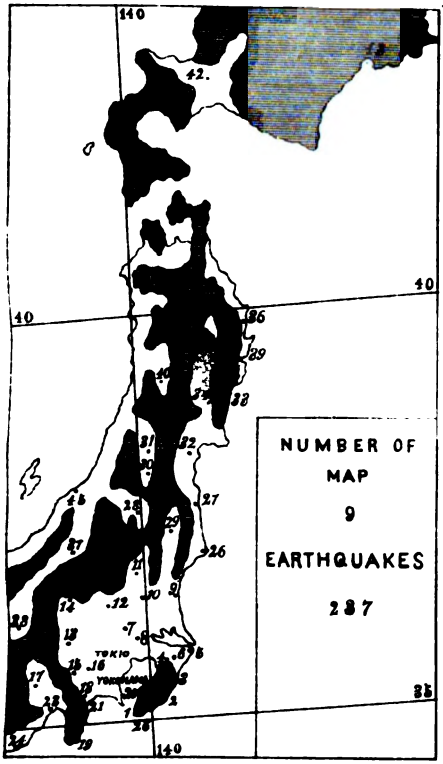

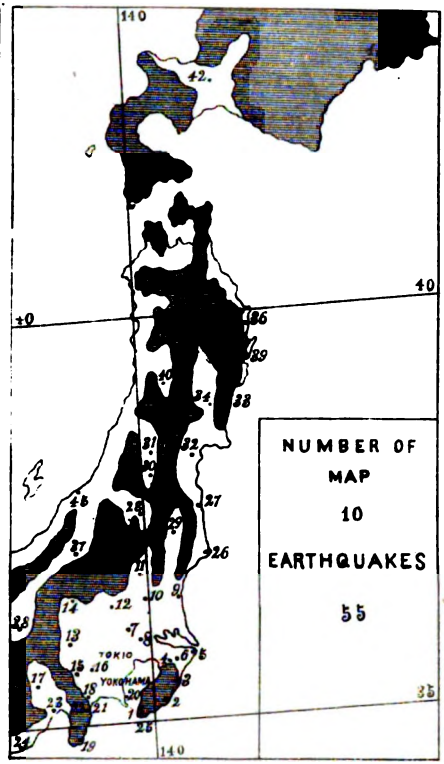

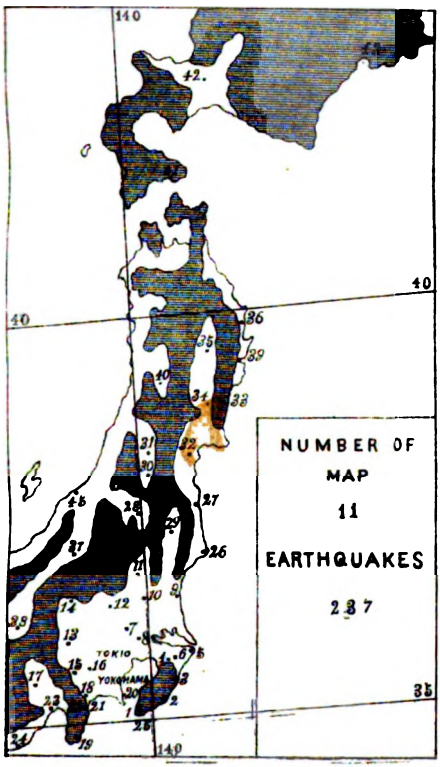

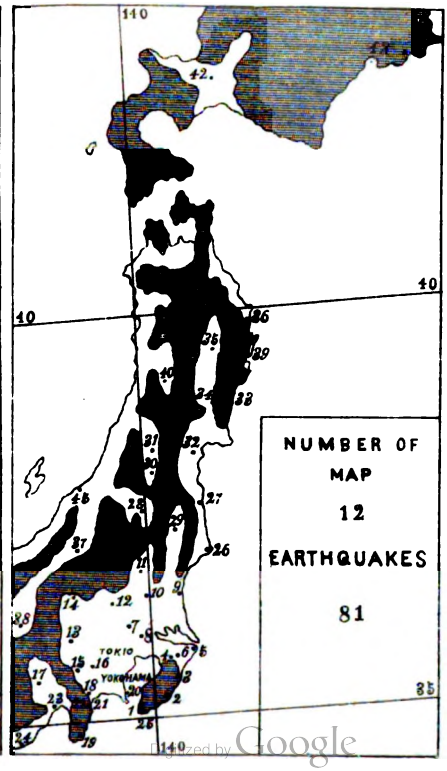

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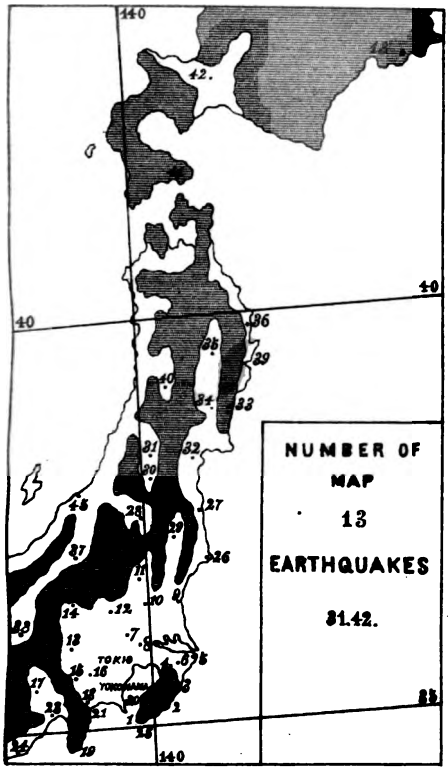

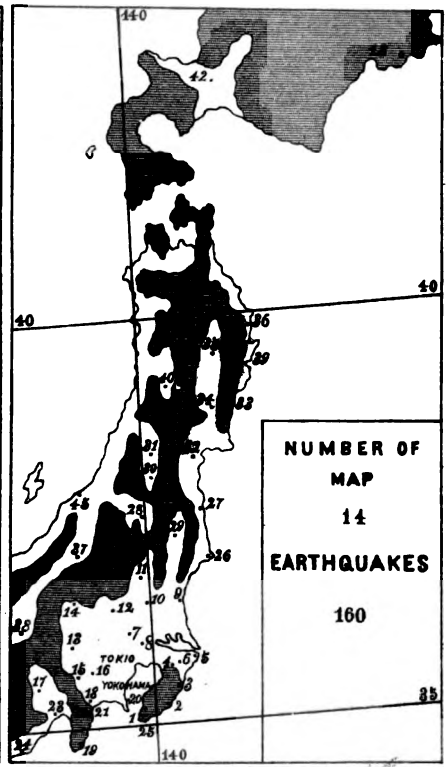

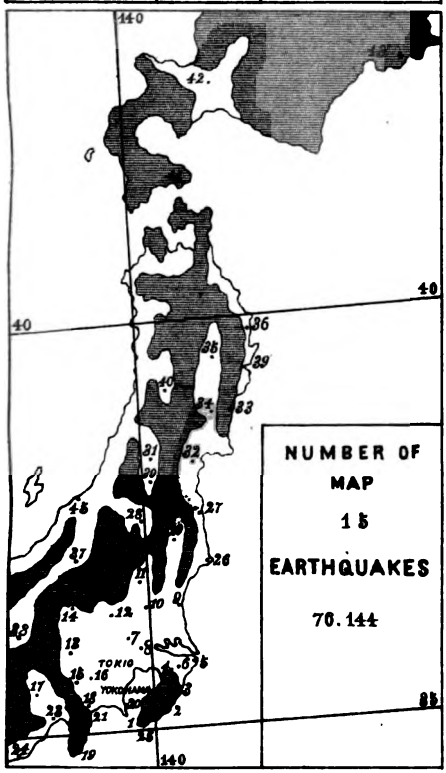

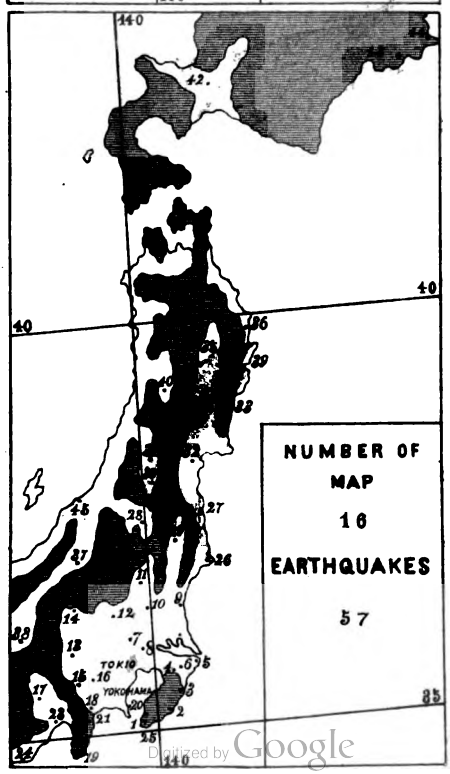

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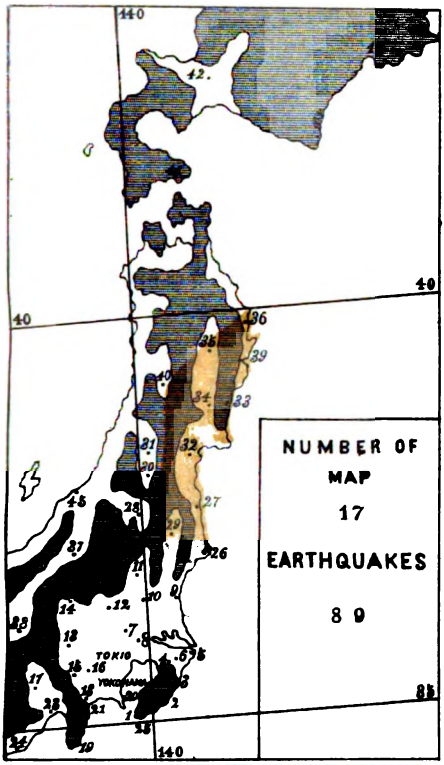

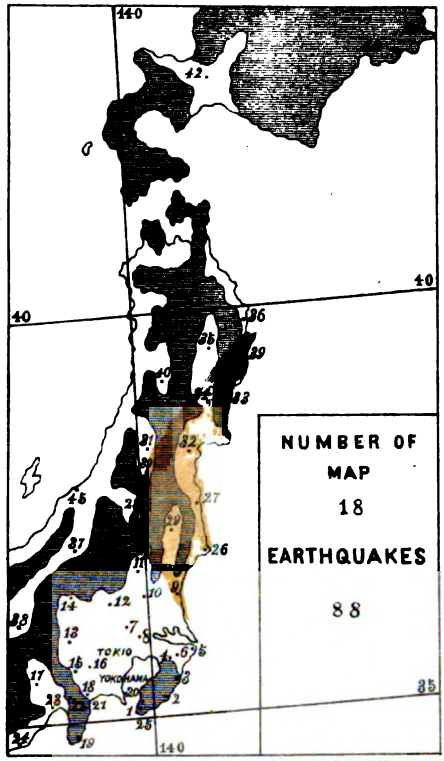

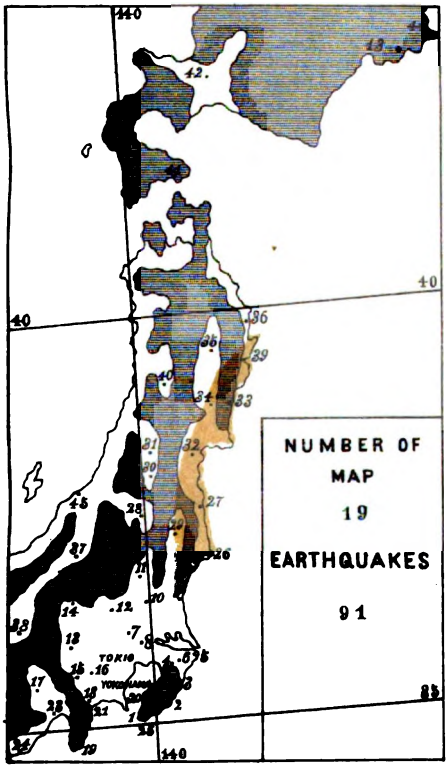

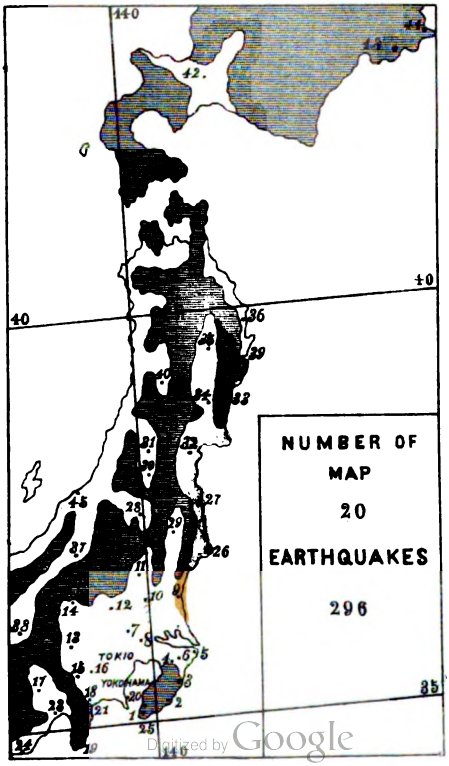

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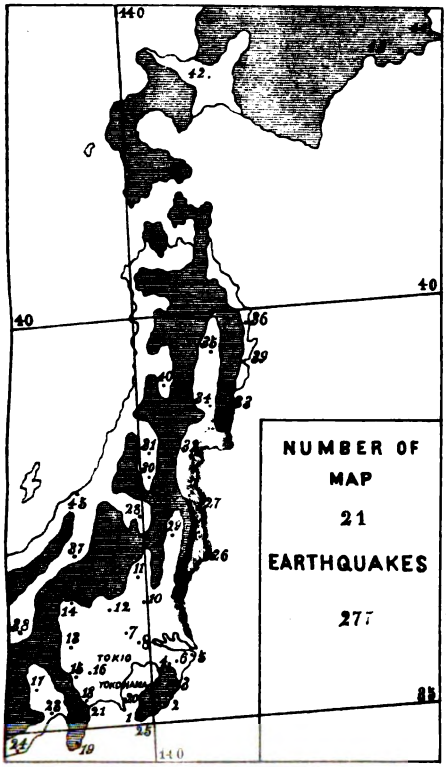

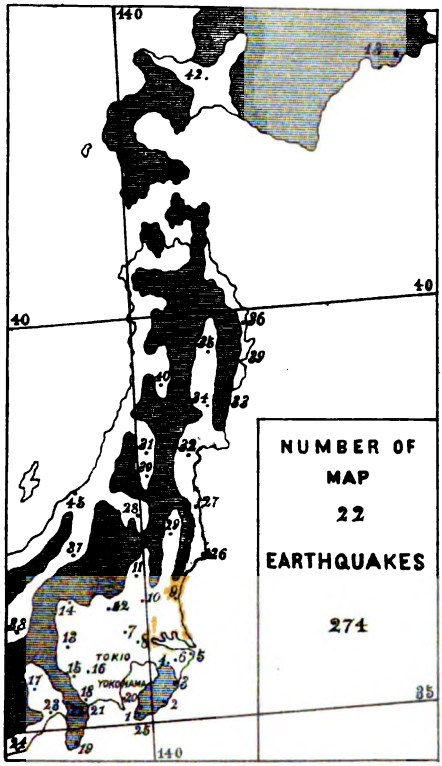

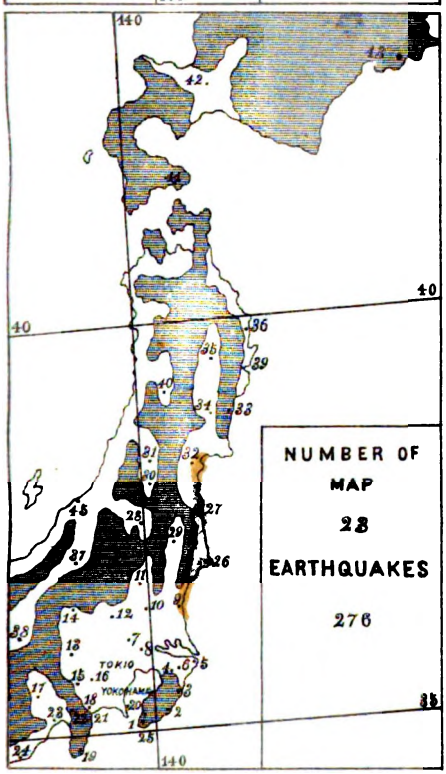

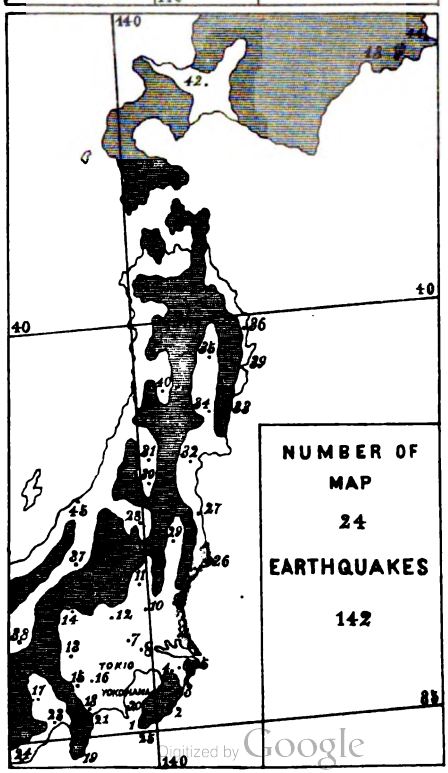

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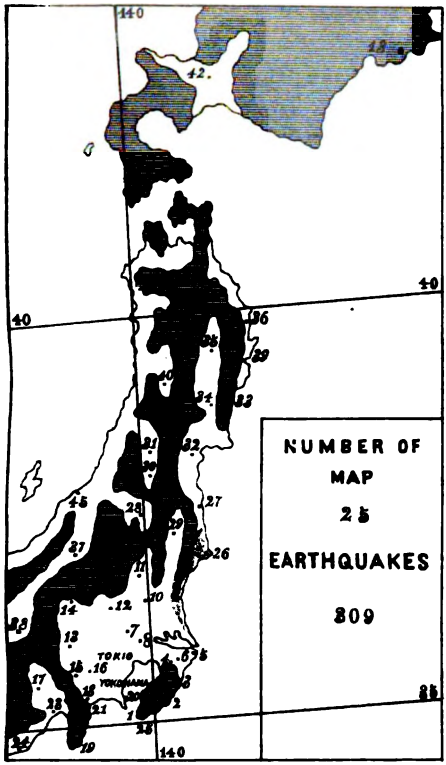
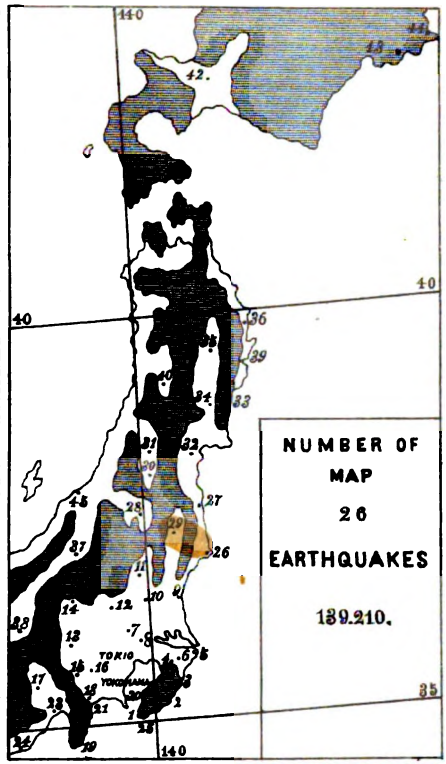
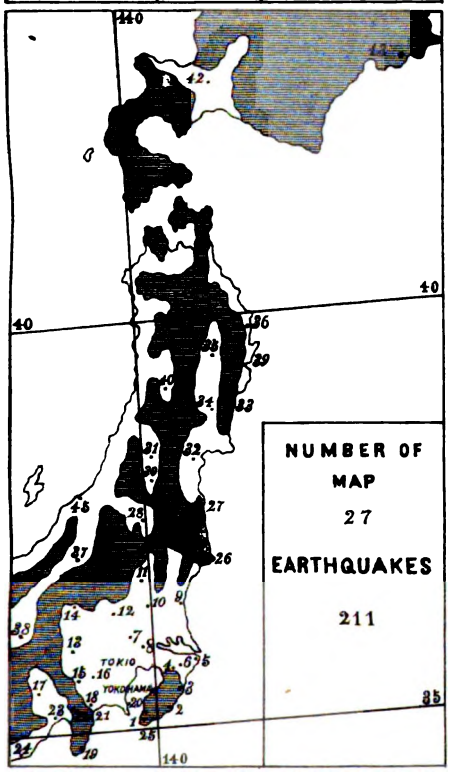


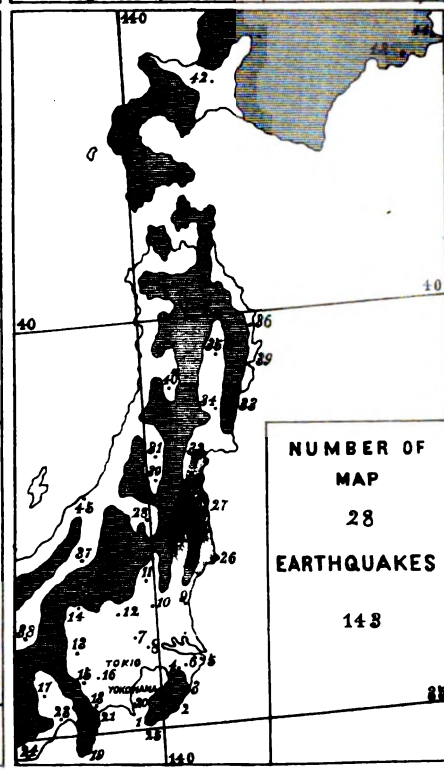
NUMBER OF MAP 25 EARTHQUAKES 309



NUMBER OF MAP 26 EARTHQUAKES 139.210.



NUMBER OF MAP 27 EARTHQUAKES 211



NUMBER OF MAP 28 EARTHQUAKES 143

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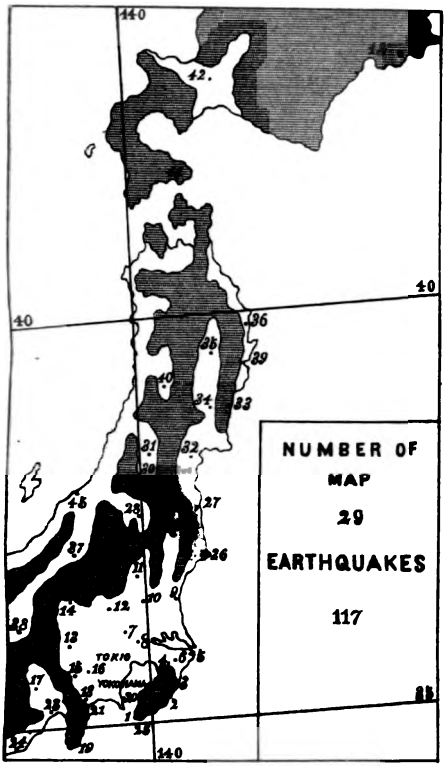

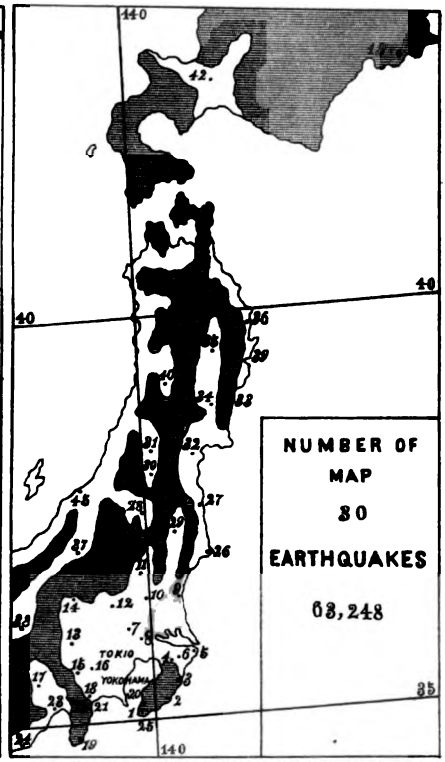

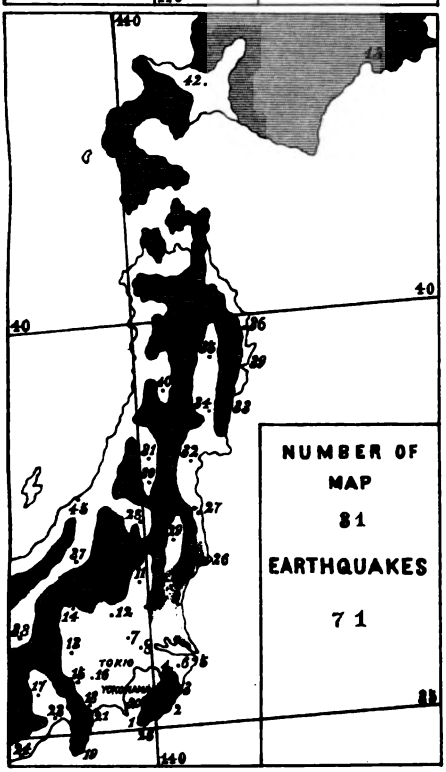

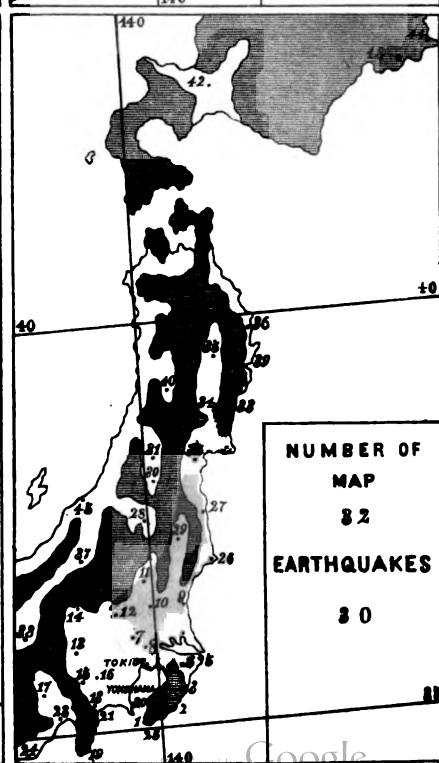

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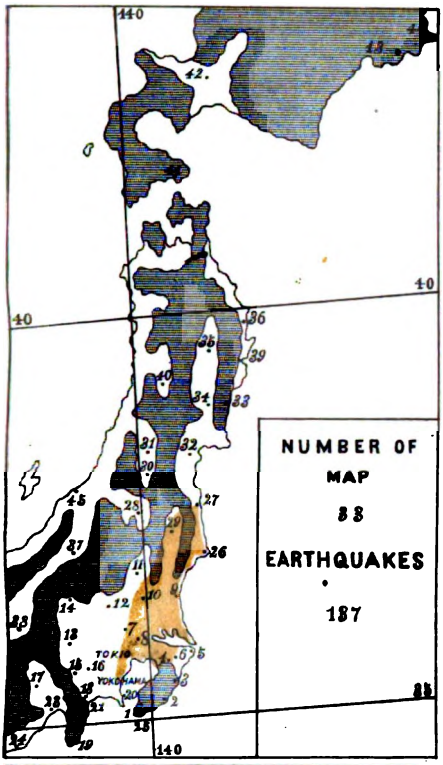

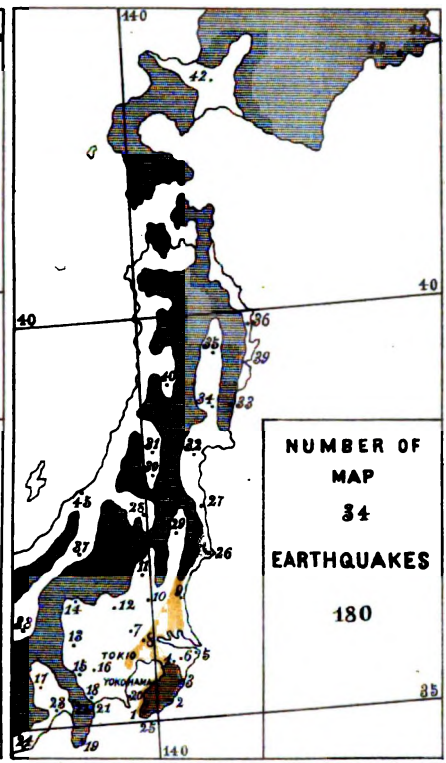

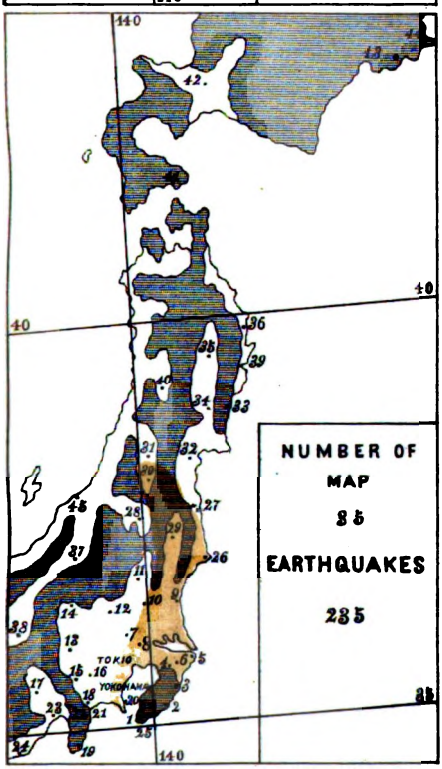

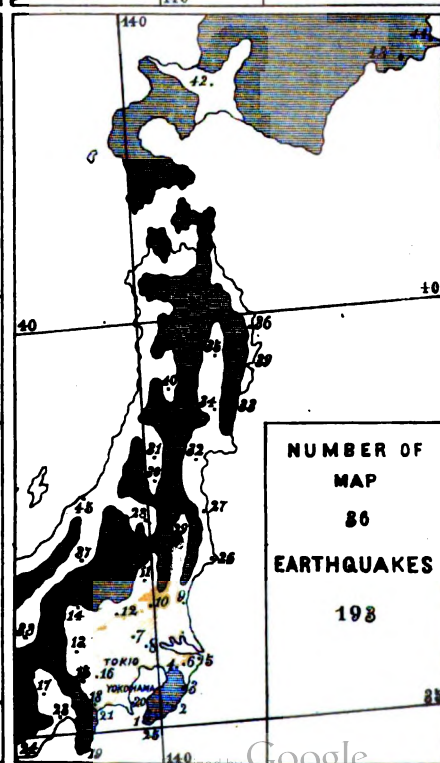

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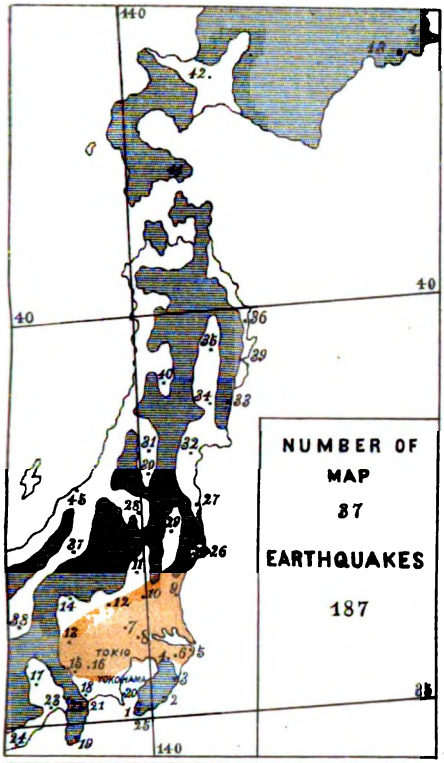

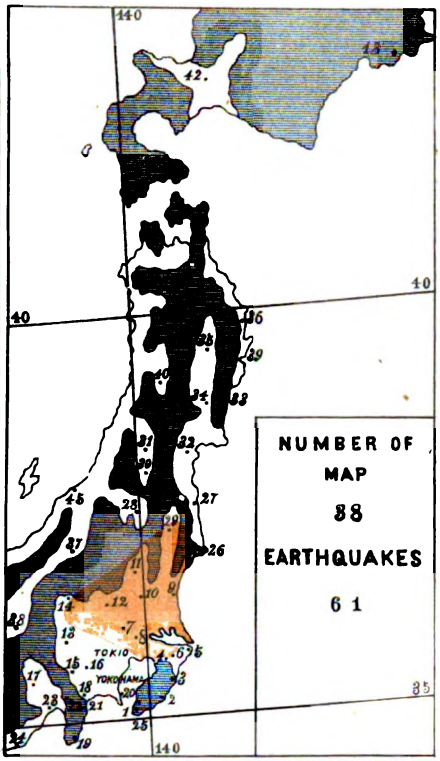

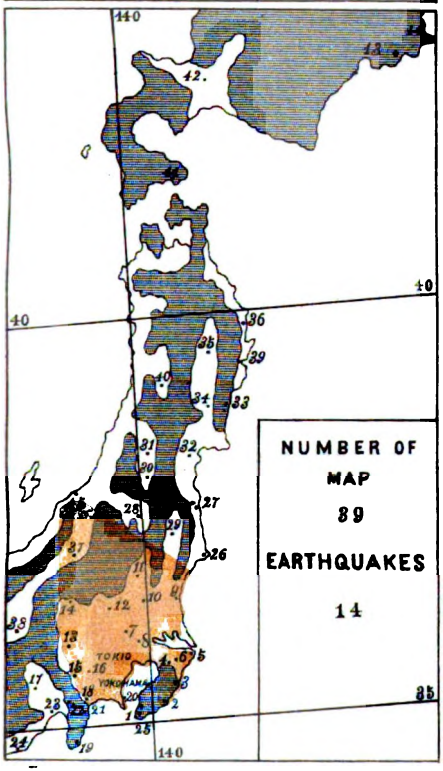

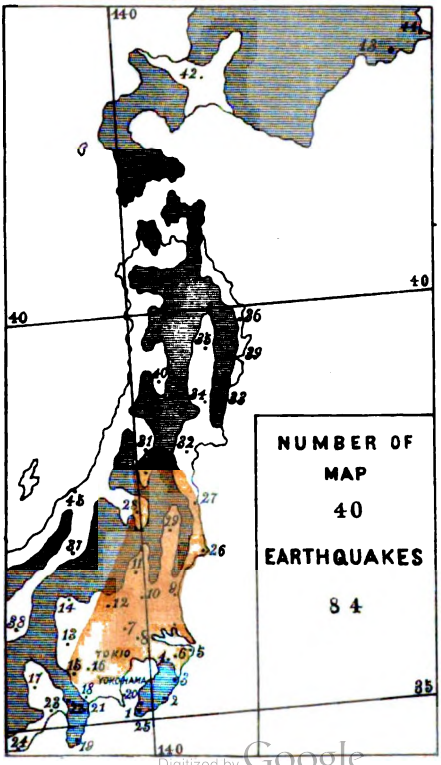

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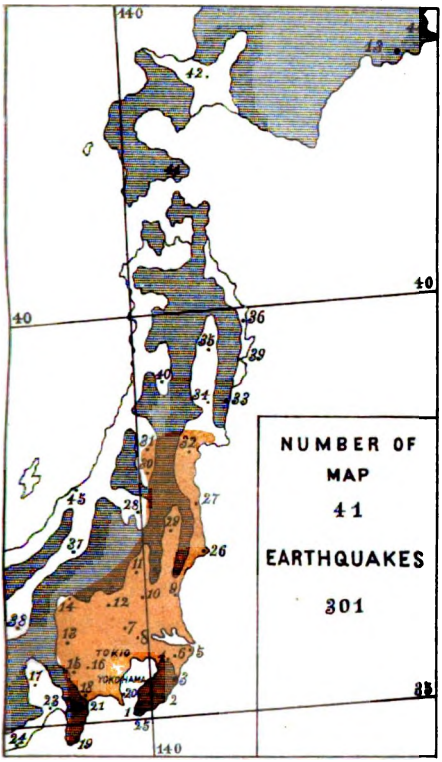

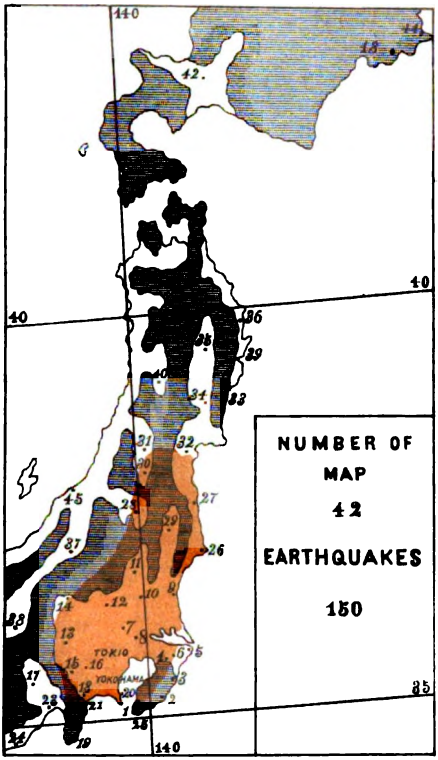

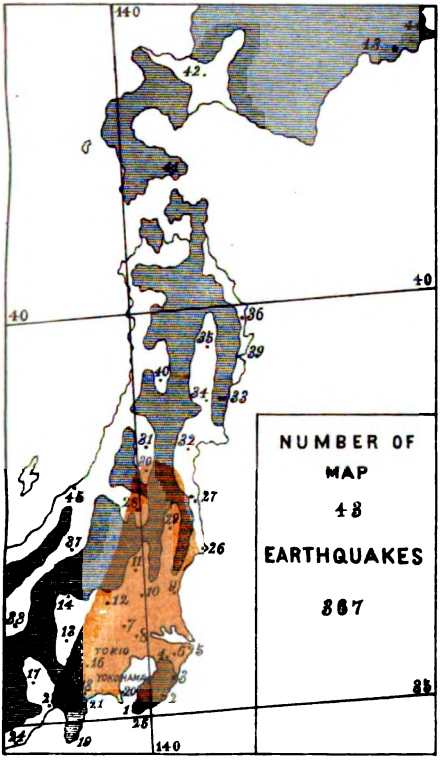

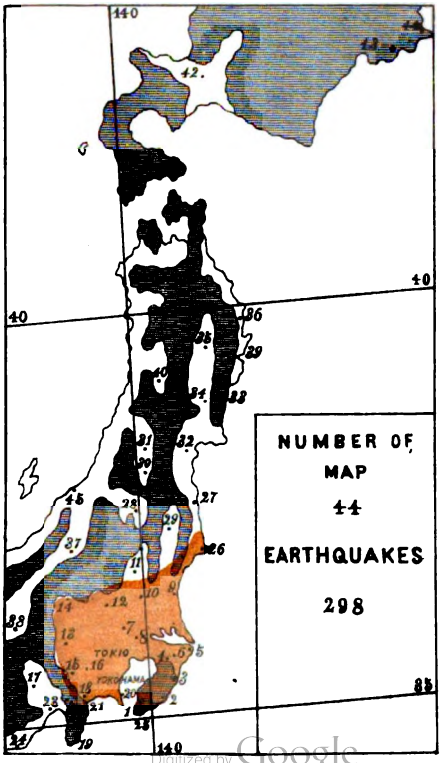

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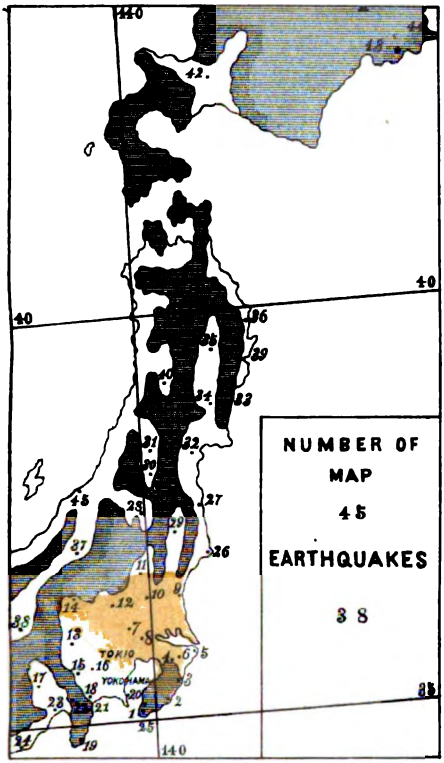

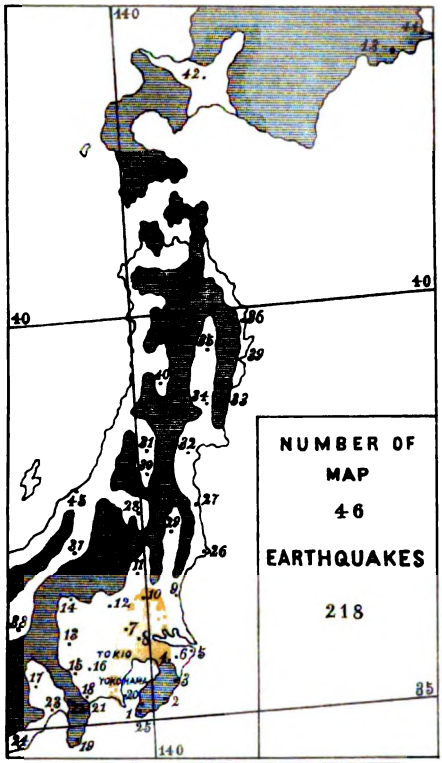

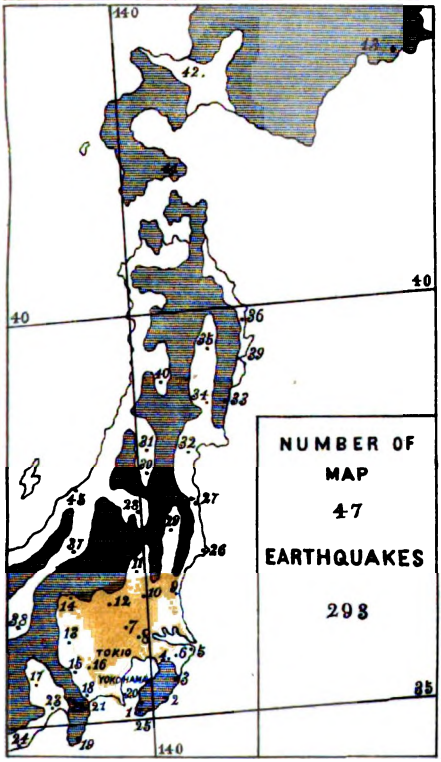

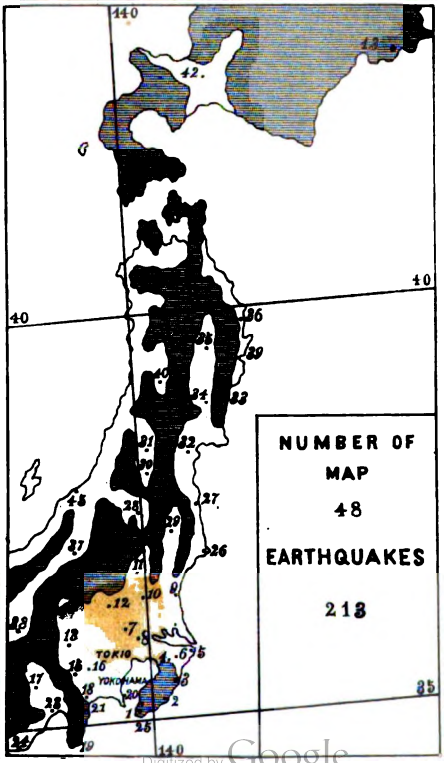

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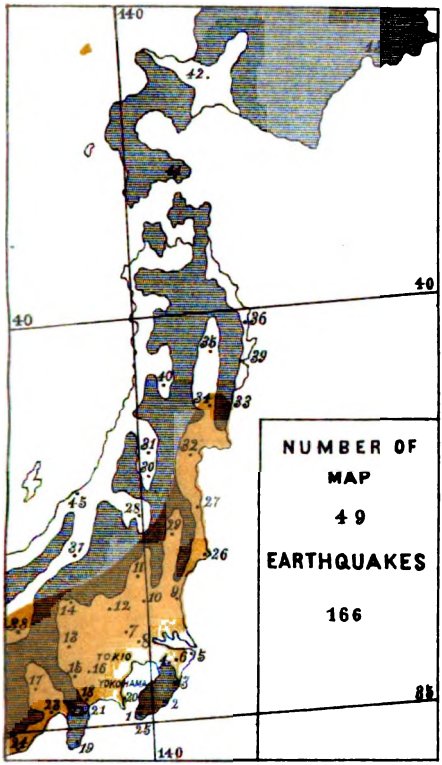

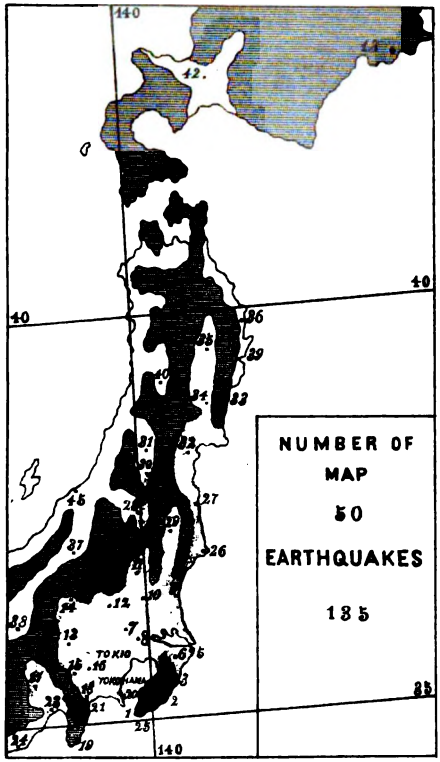

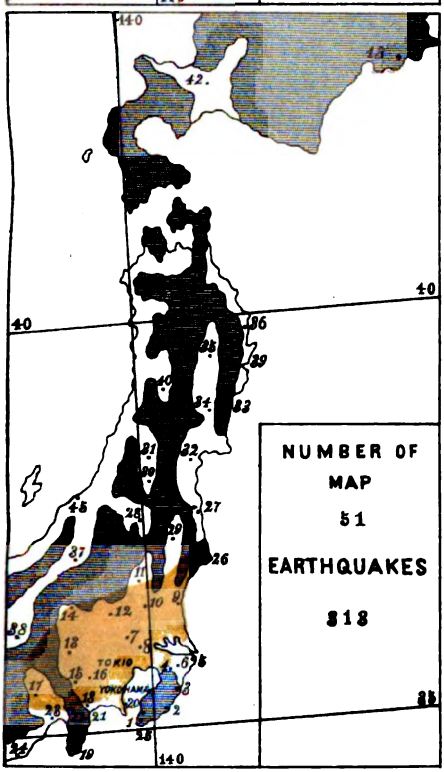

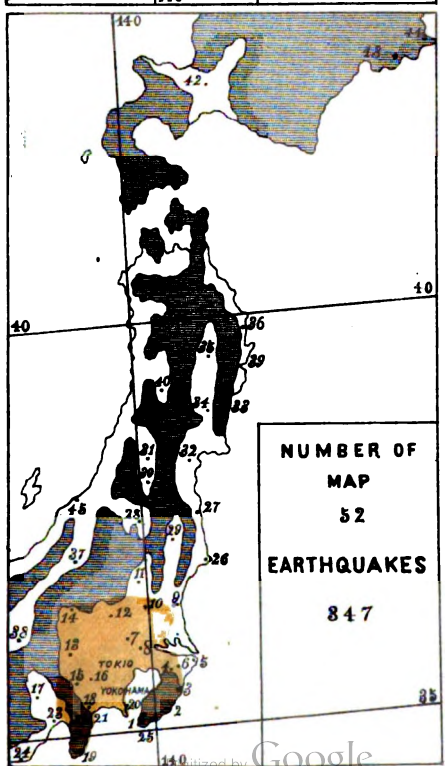

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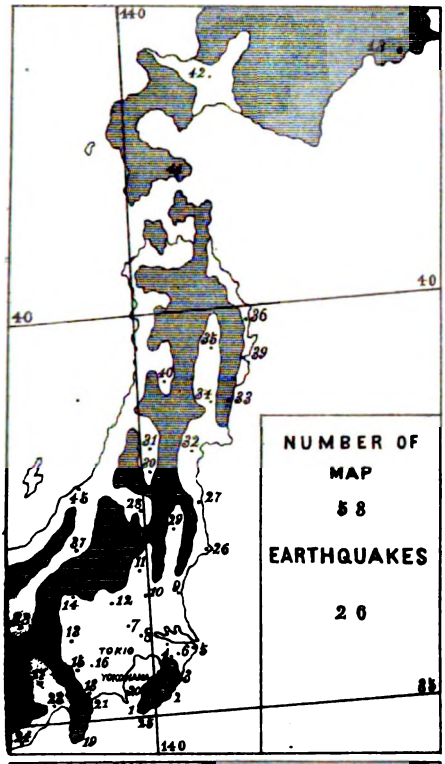

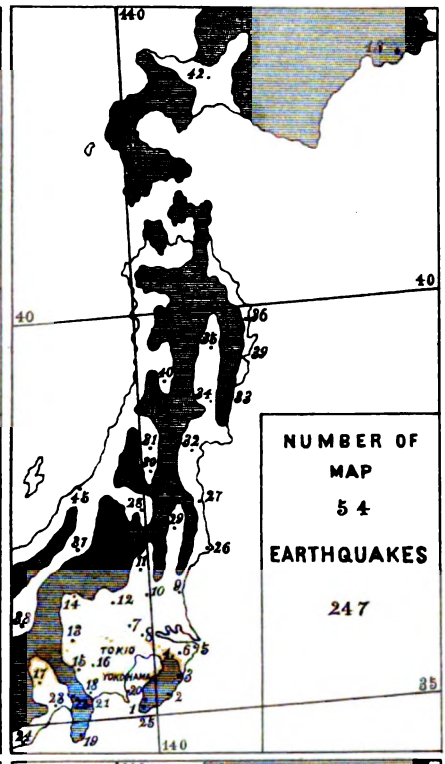

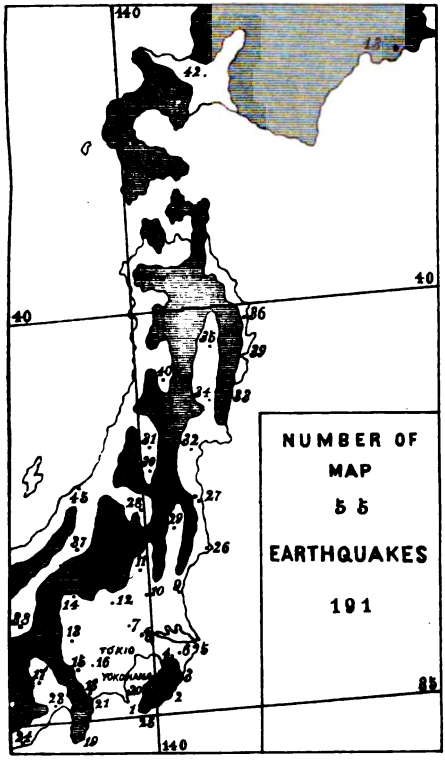

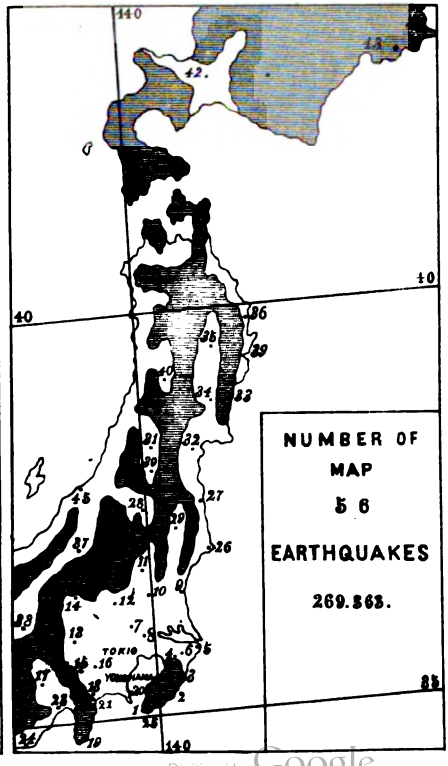

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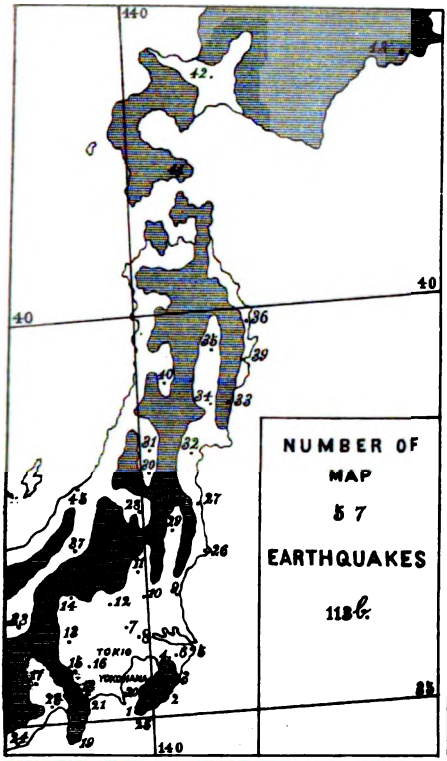

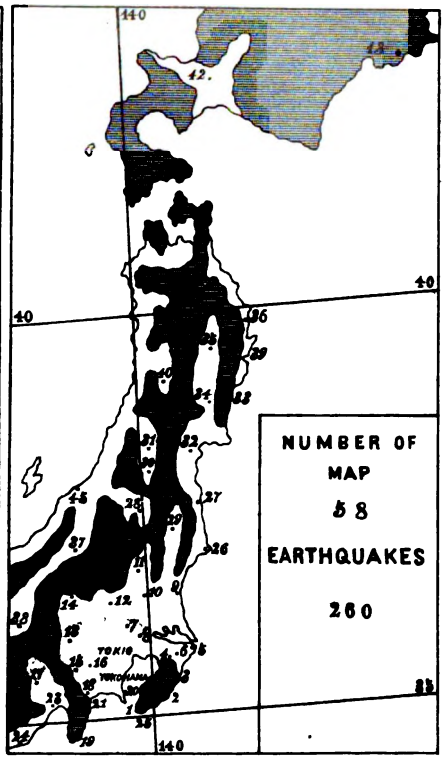

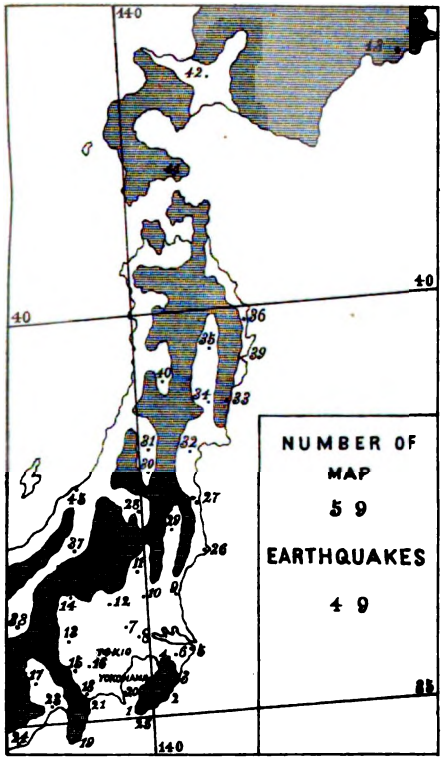

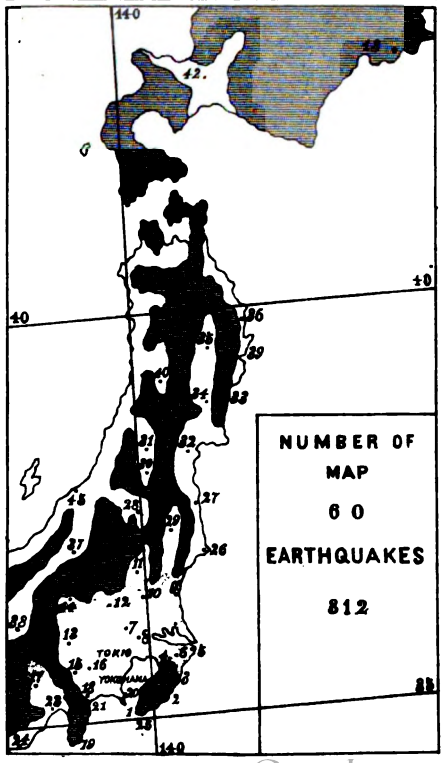

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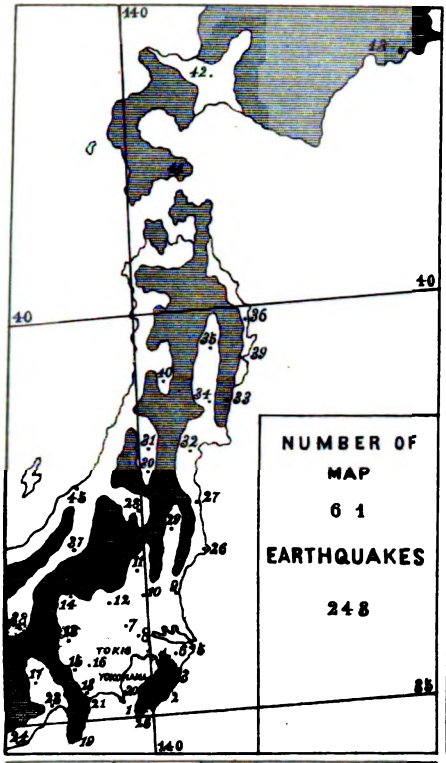

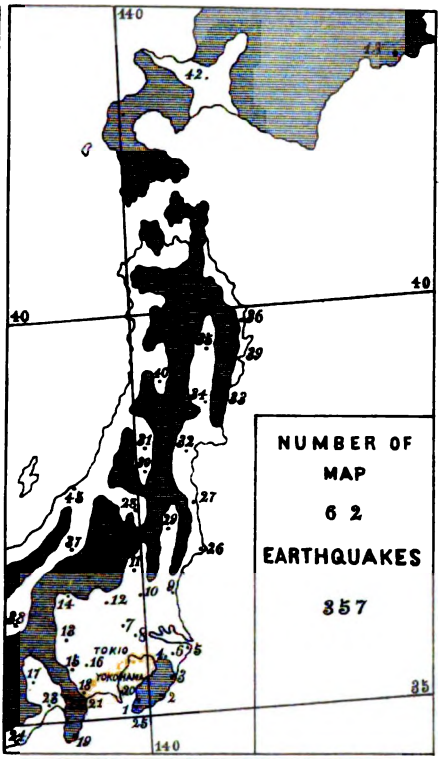

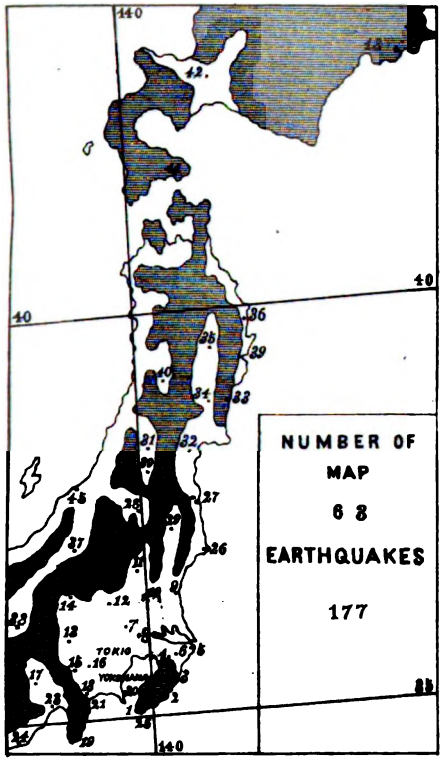

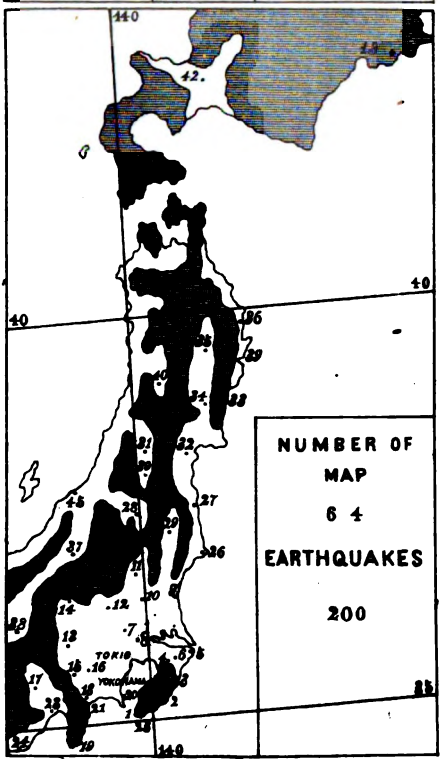

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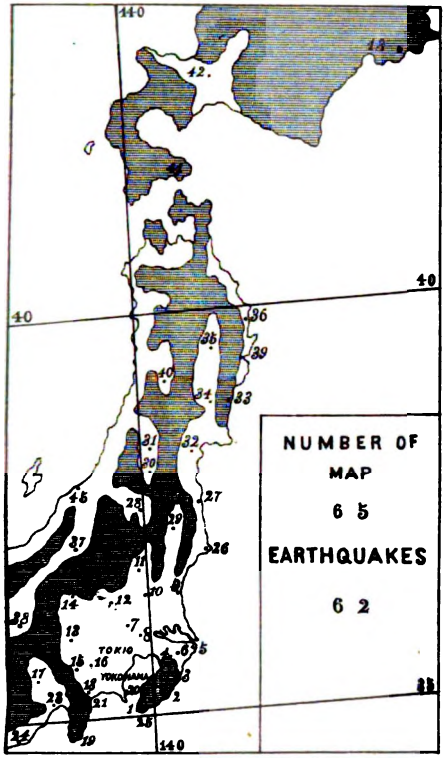
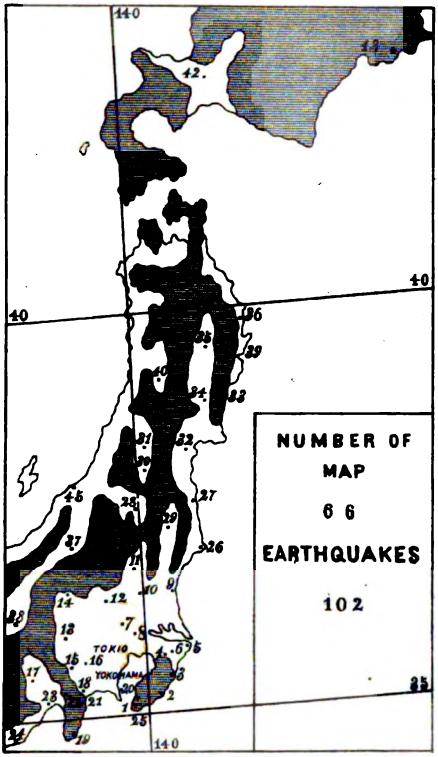
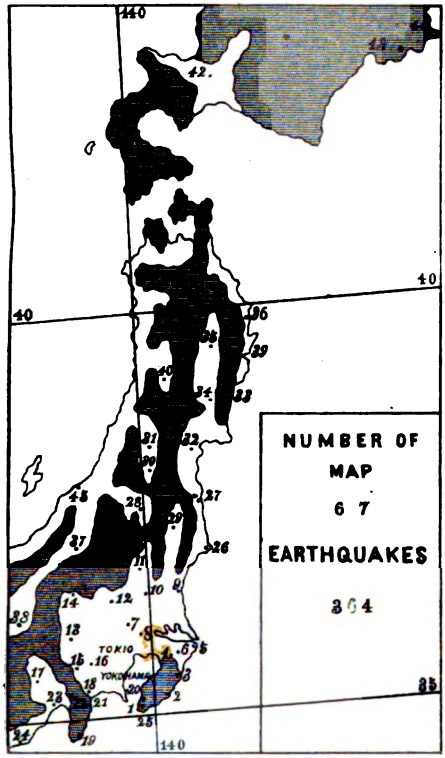


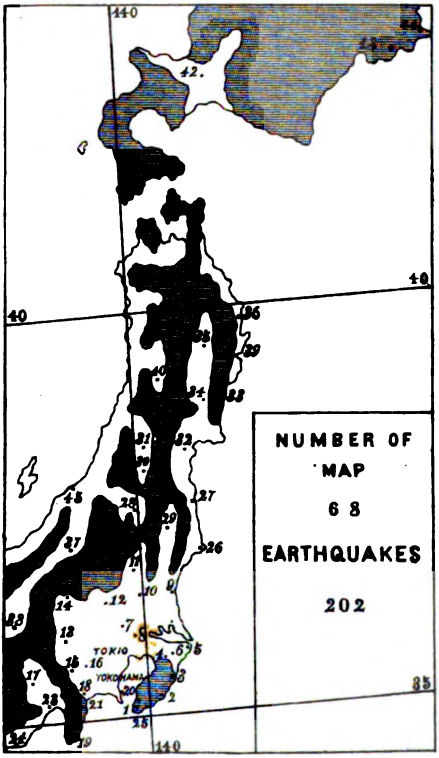
NUMBER OF MAP 65
EARTHQUAKES 62



NUMBER OF MAP 66
EARTHQUAKES 102



NUMBER OF MAP 67
EARTHQUAKES 364



NUMBER OF MAP 68
EARTHQUAKES 202

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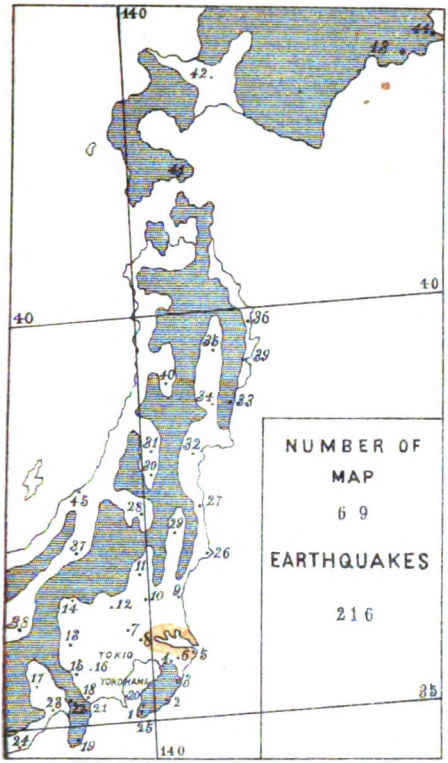

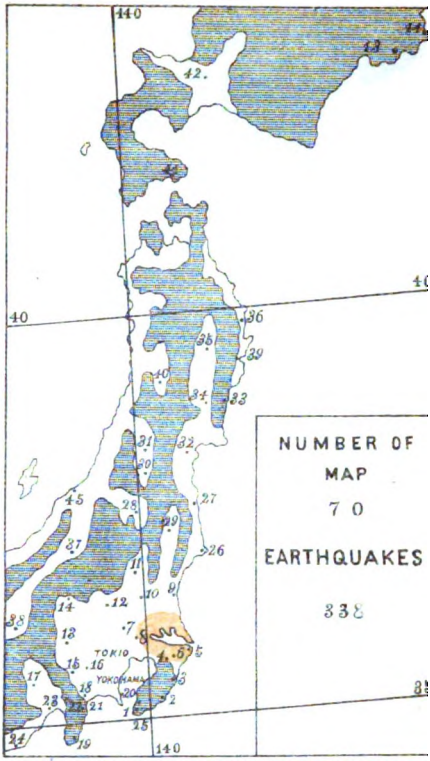

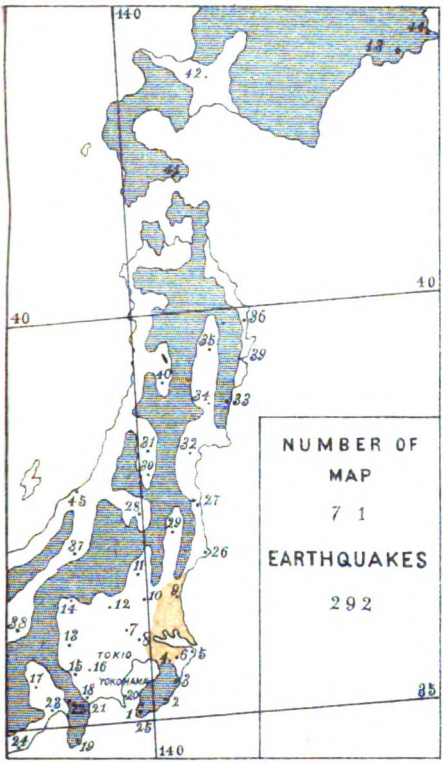

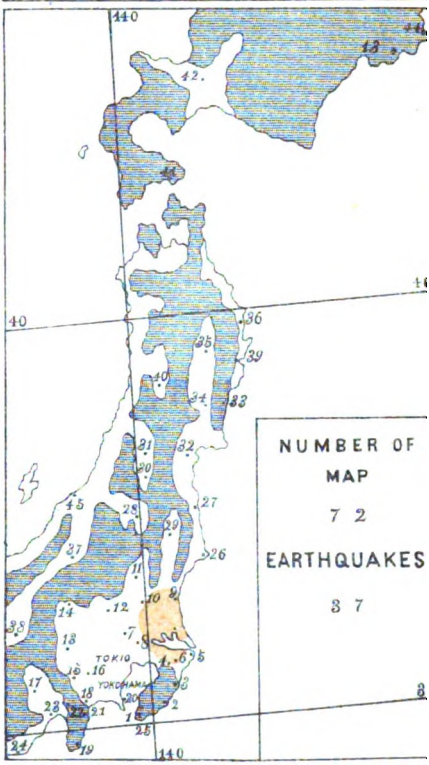

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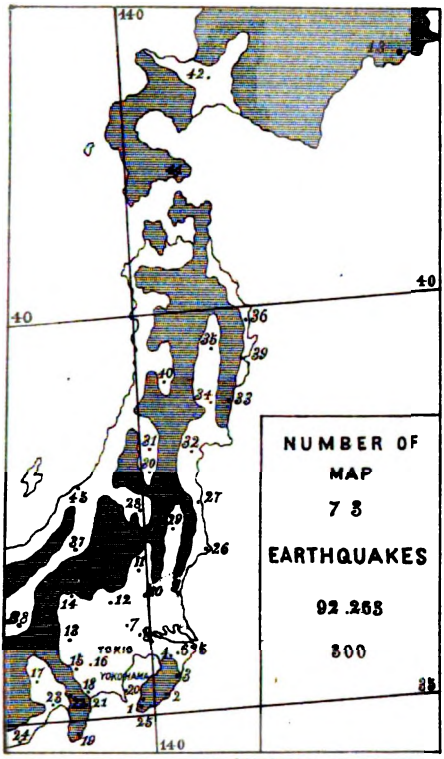

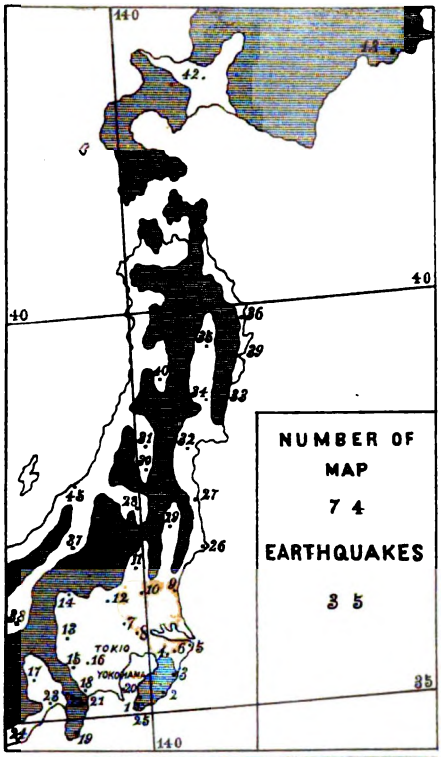

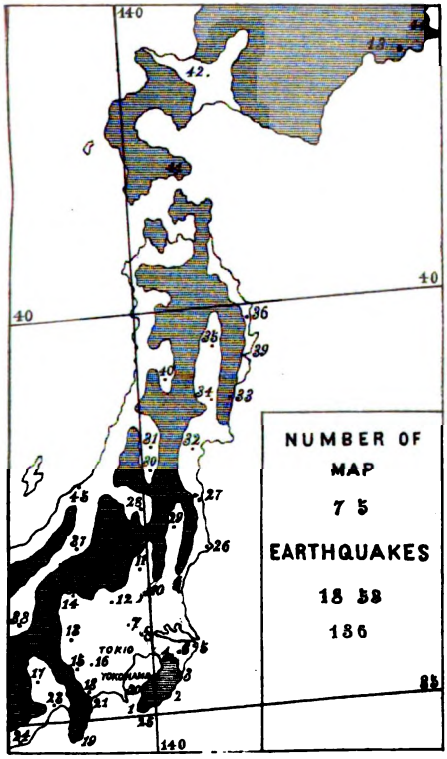

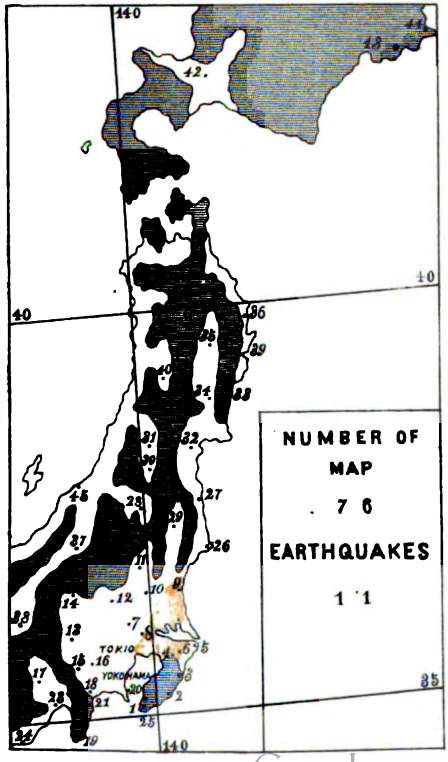

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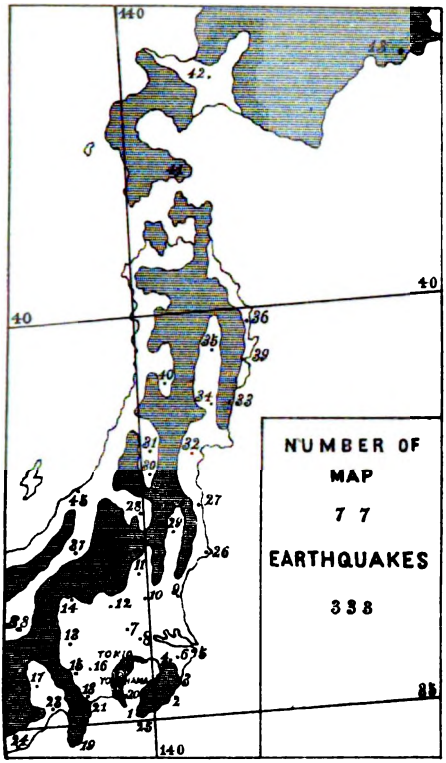

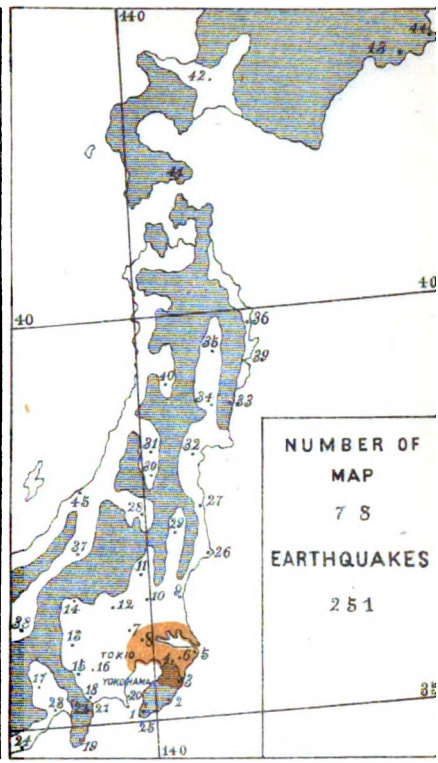

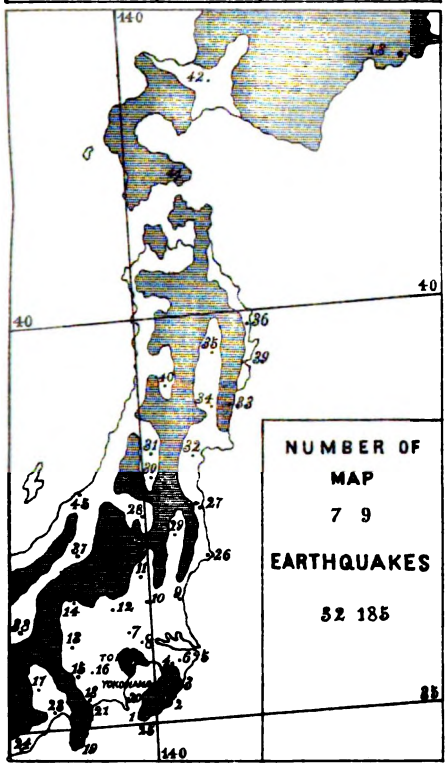

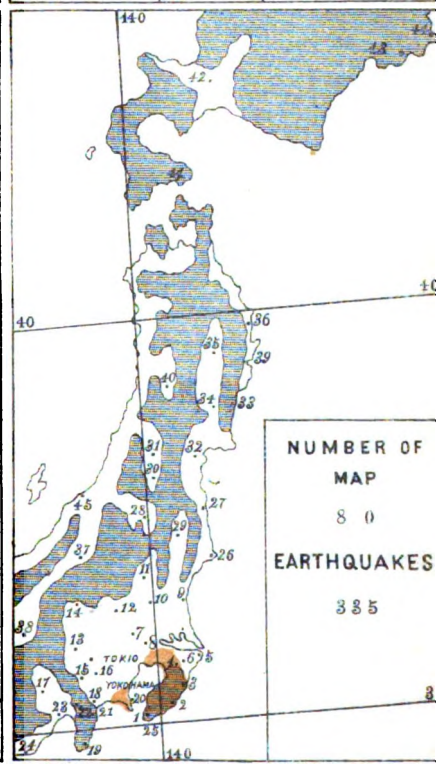

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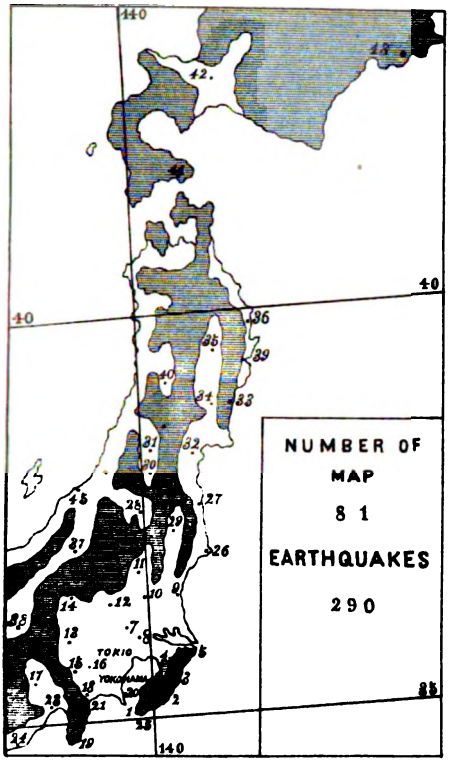

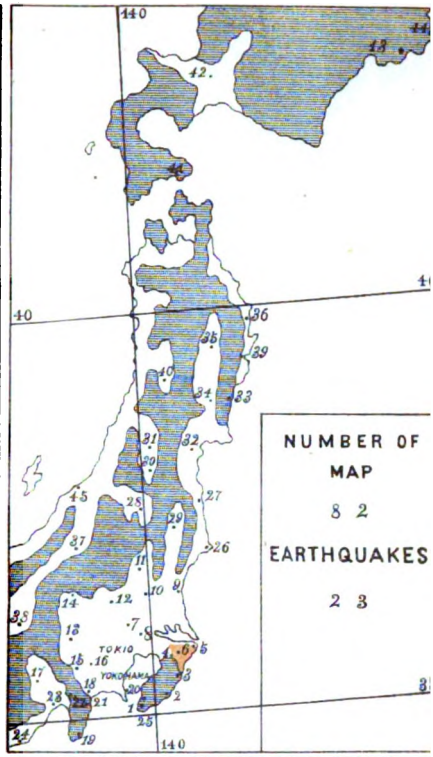

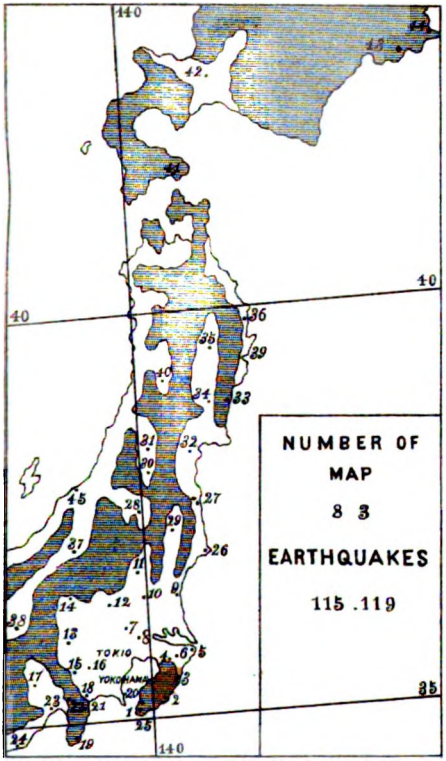

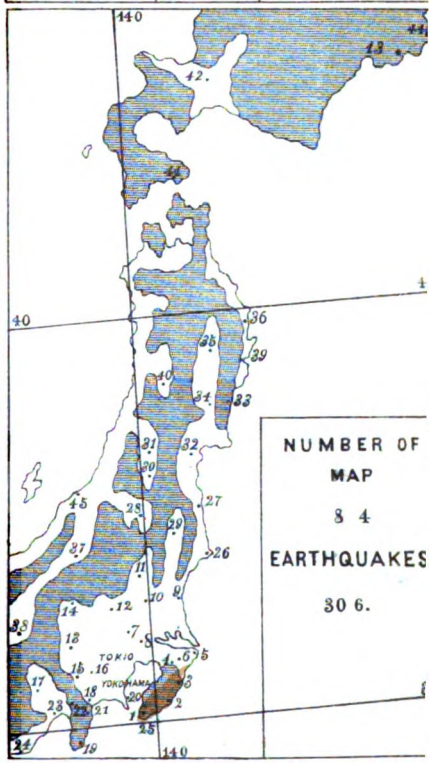

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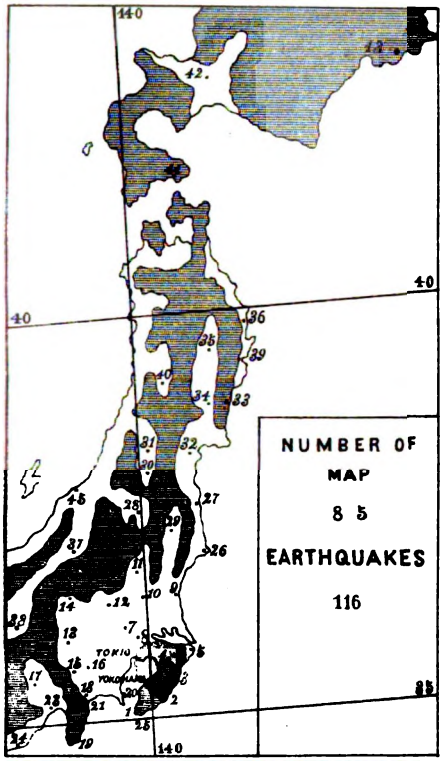

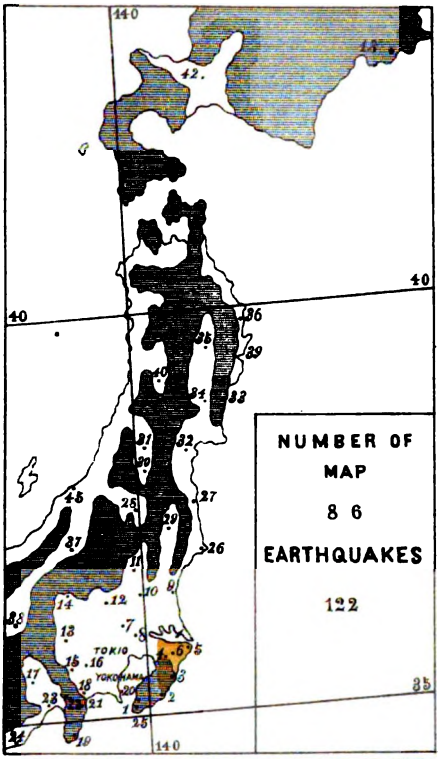

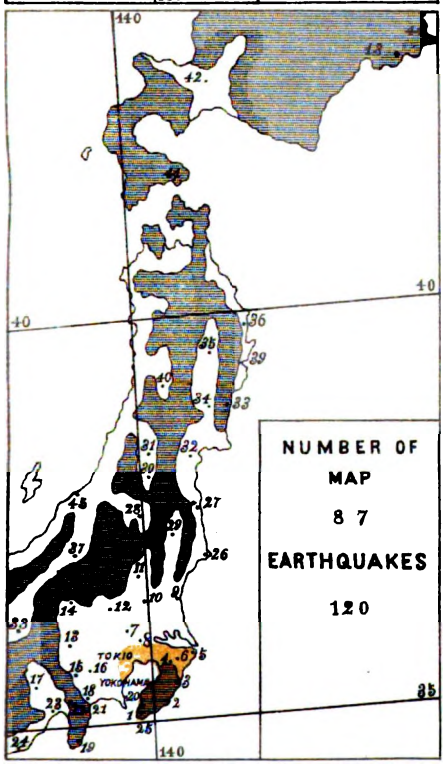

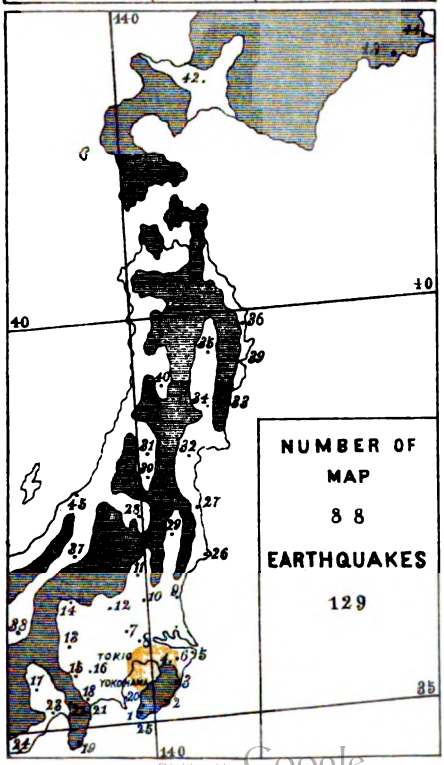

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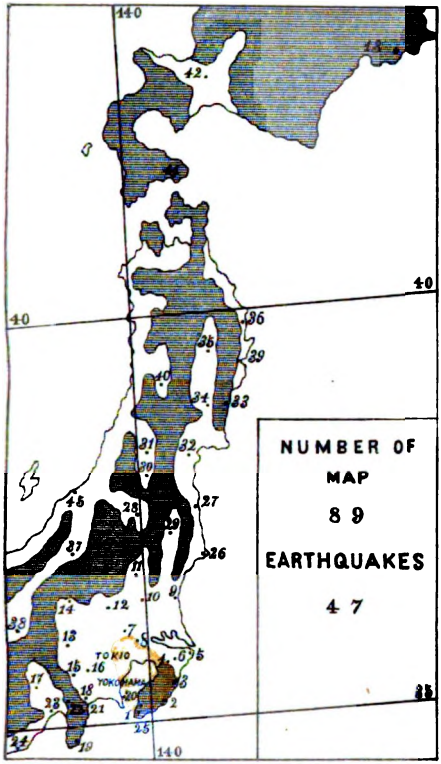

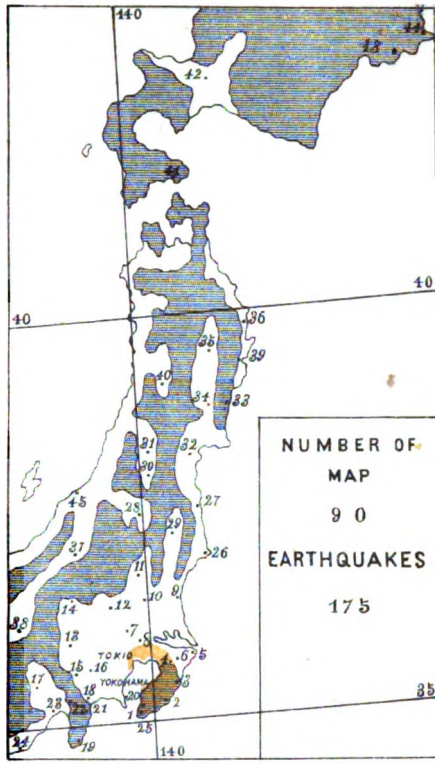

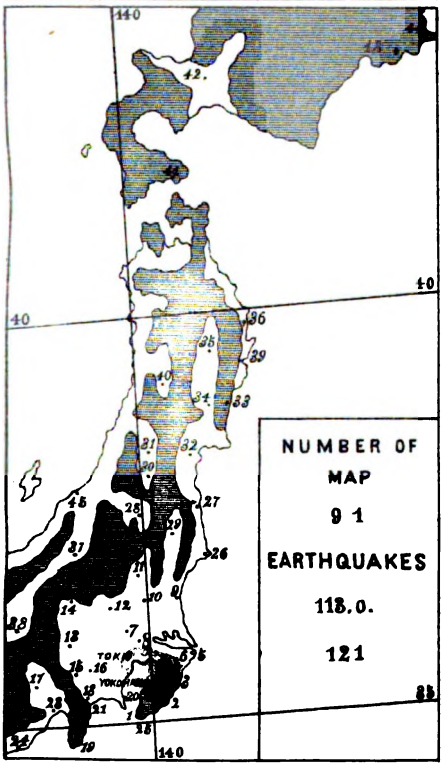

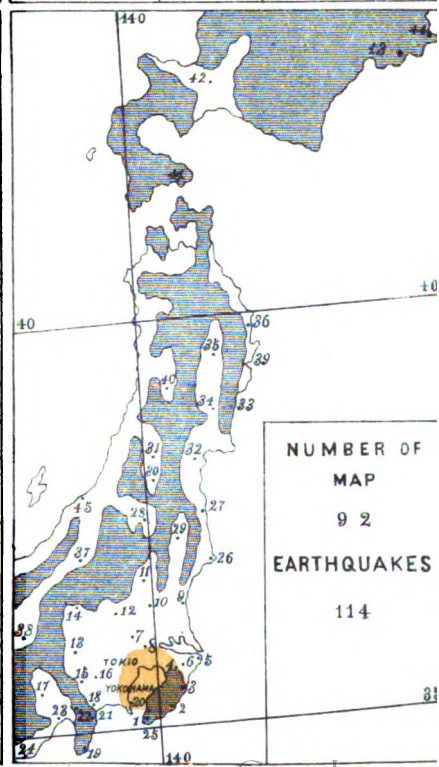

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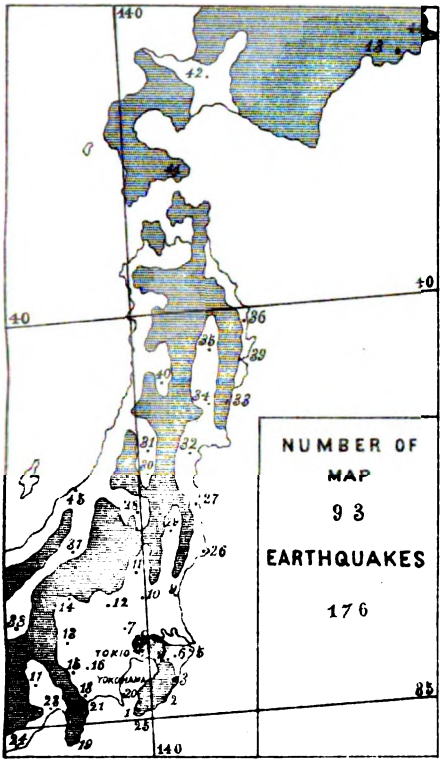

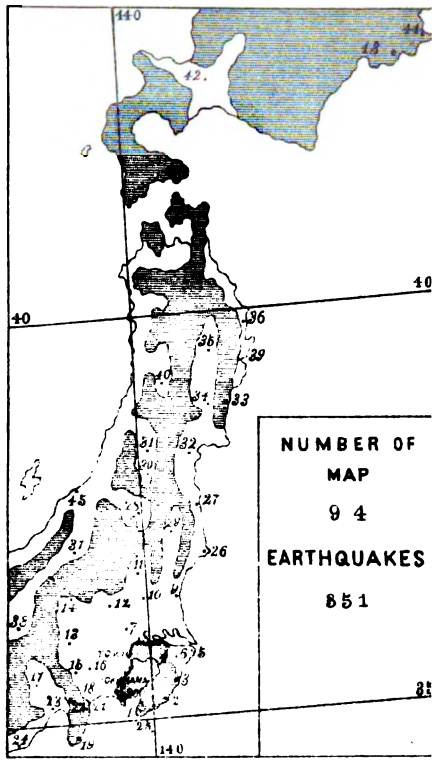

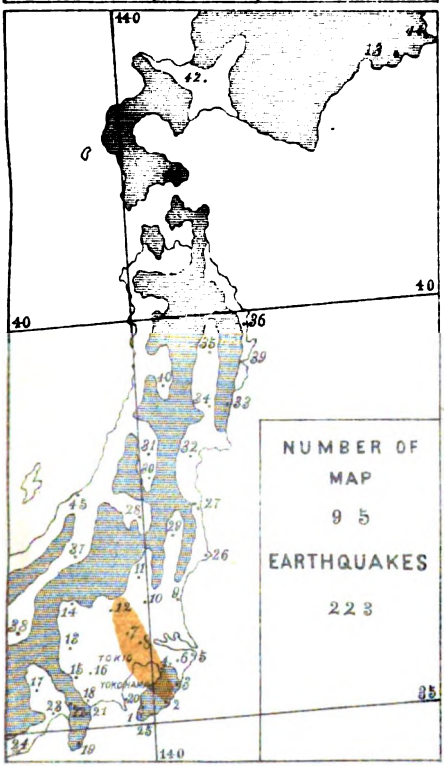

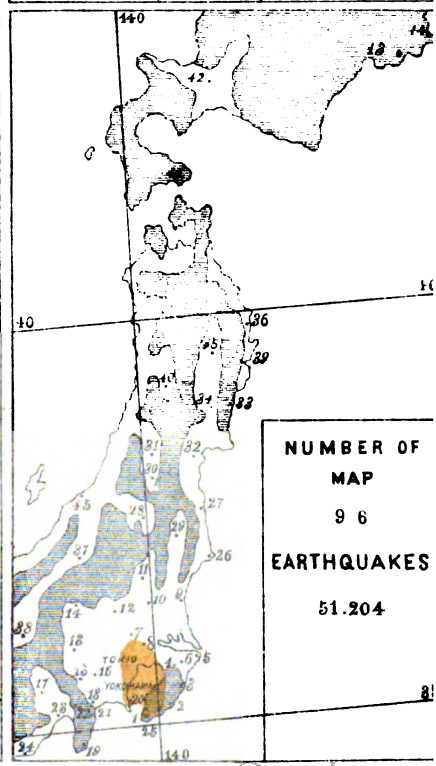

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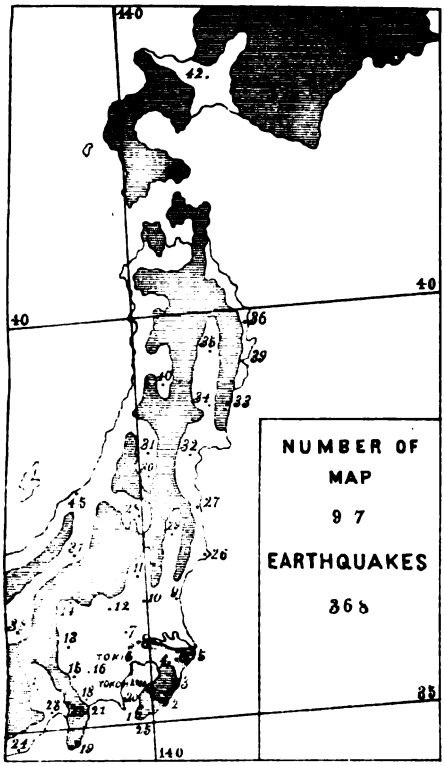

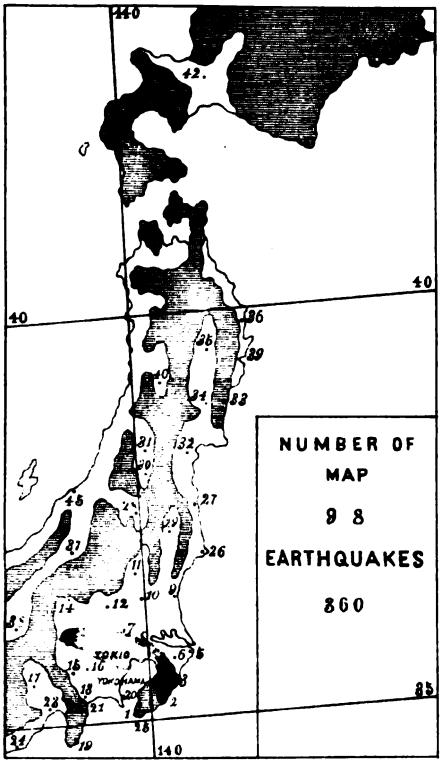

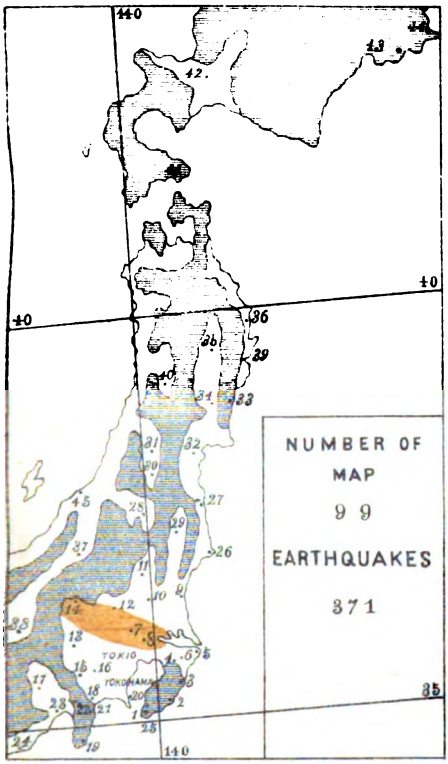

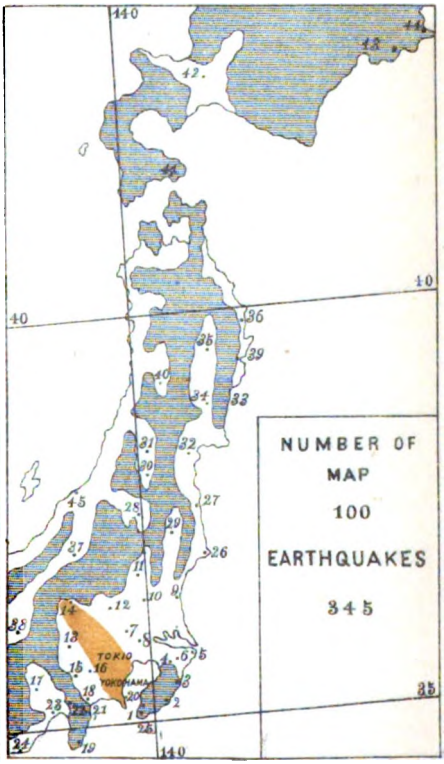

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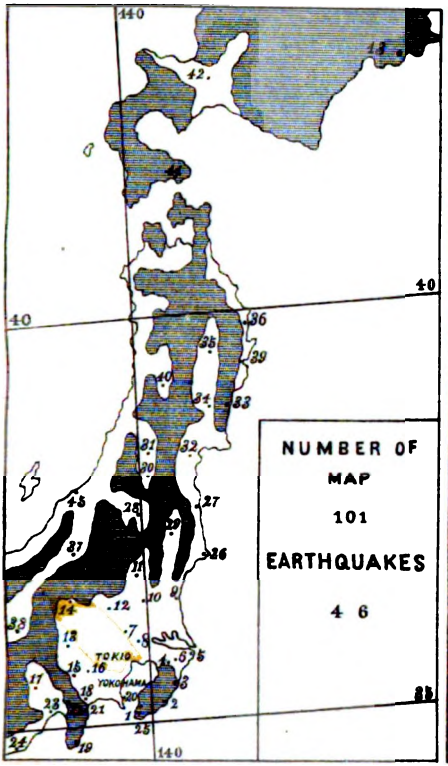

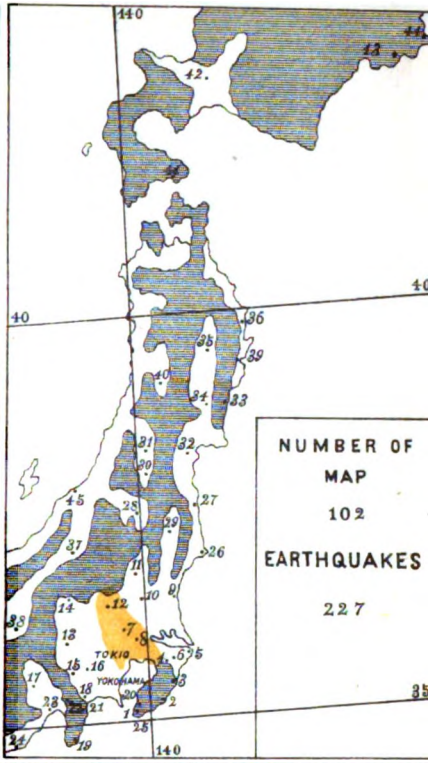

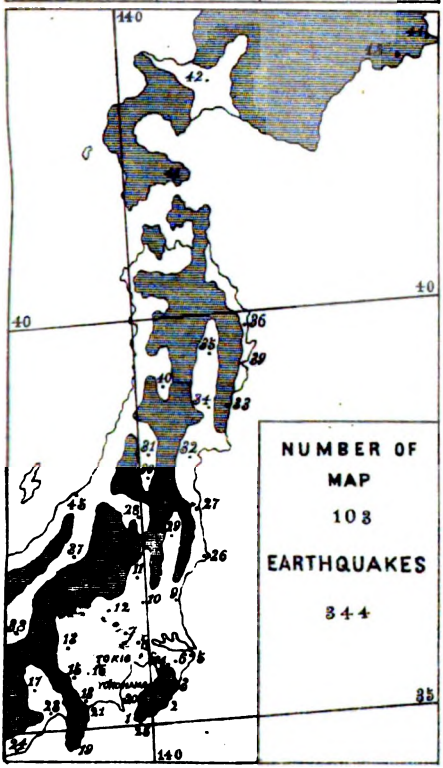

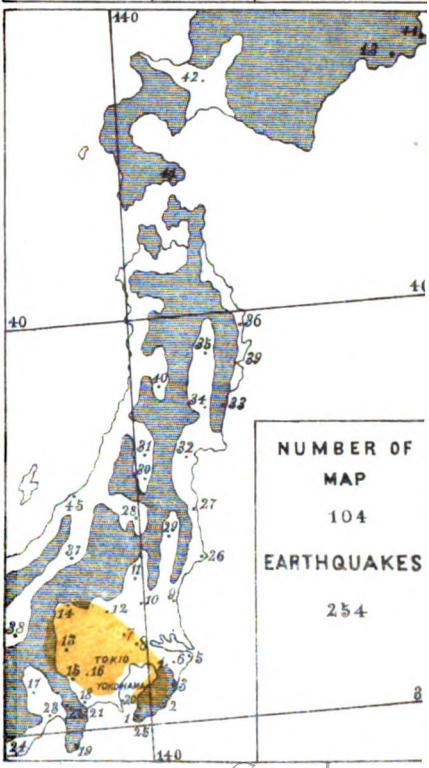

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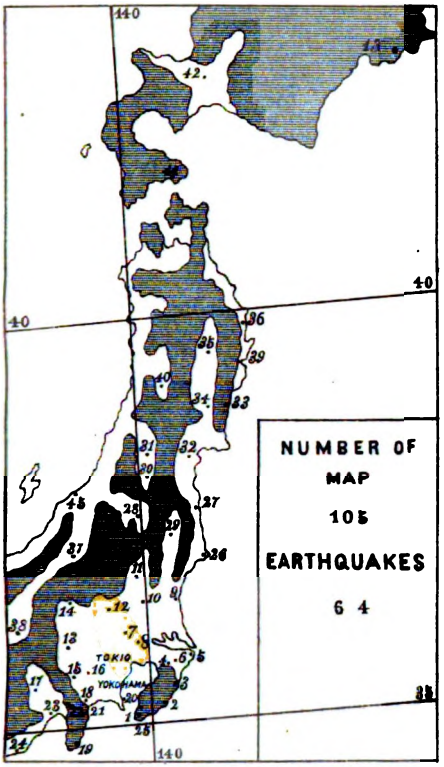

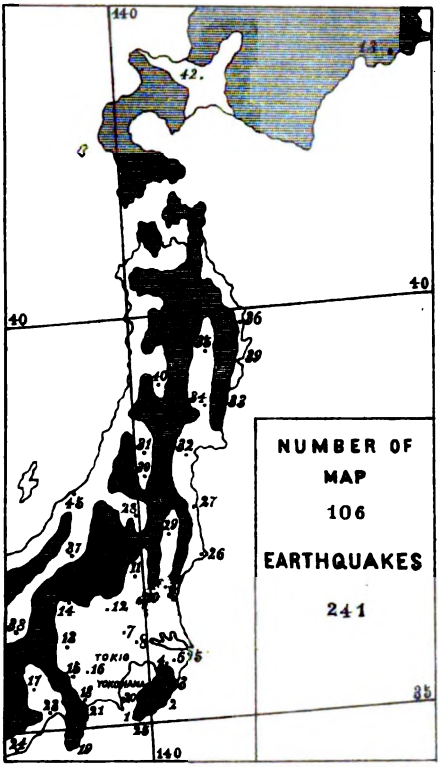

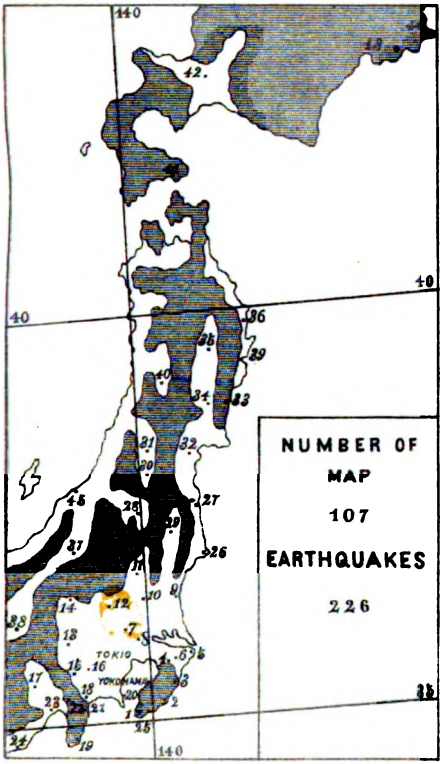

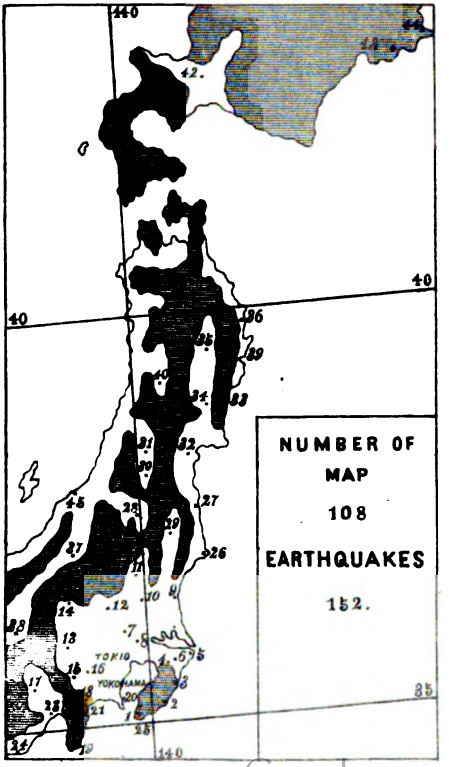

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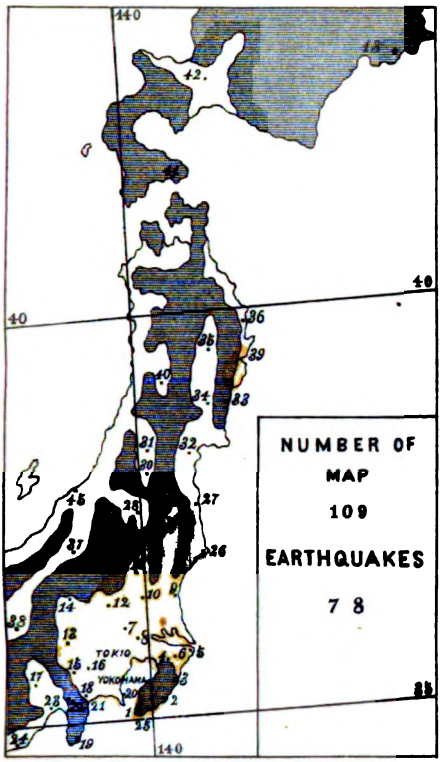

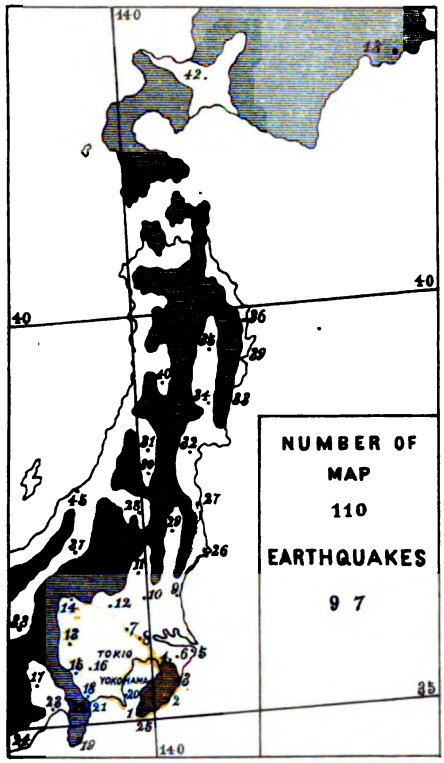

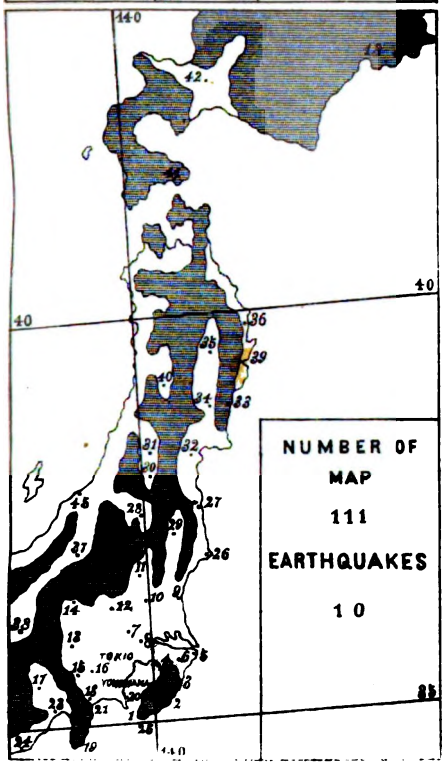

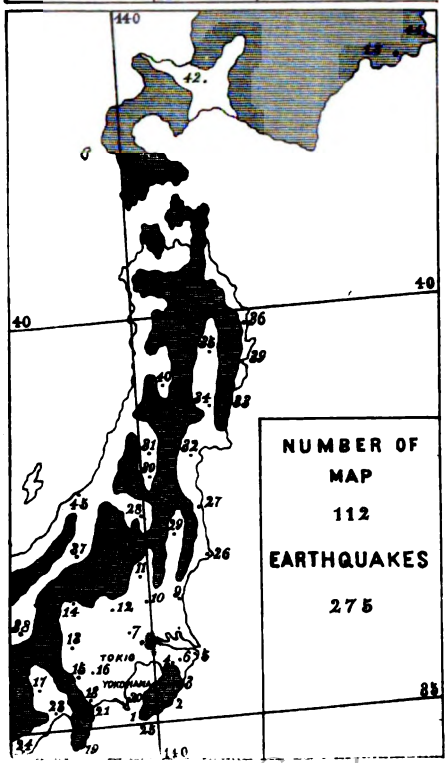

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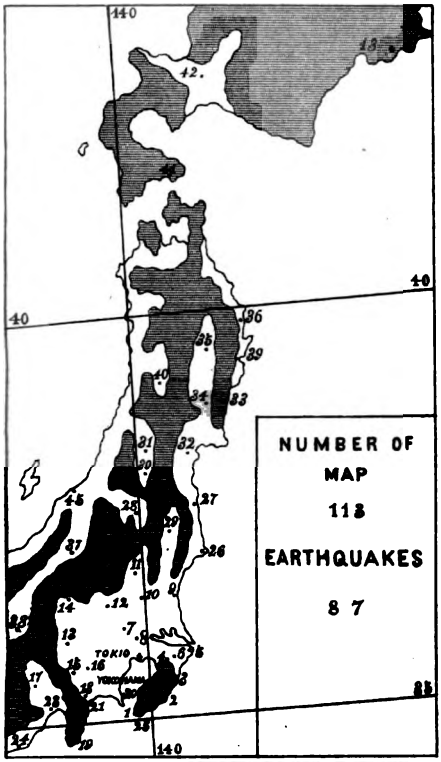

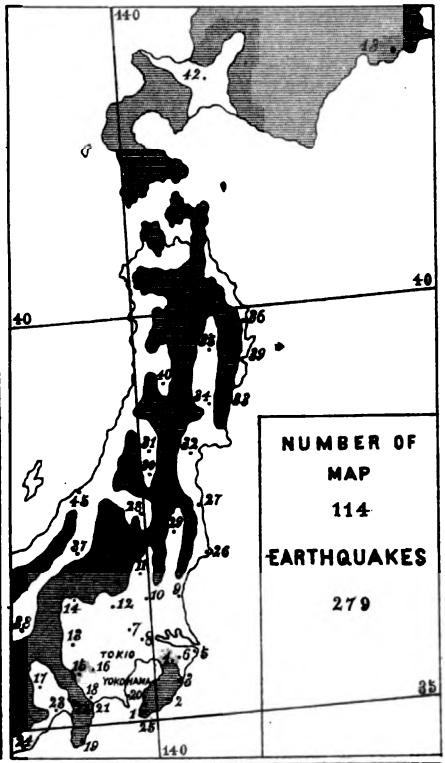

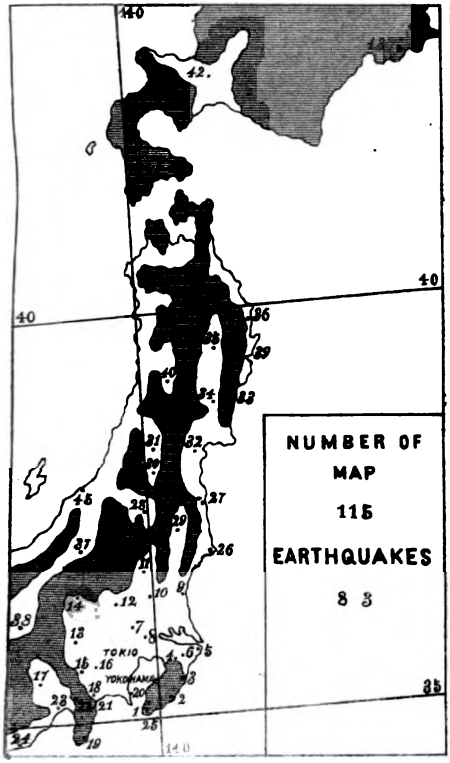

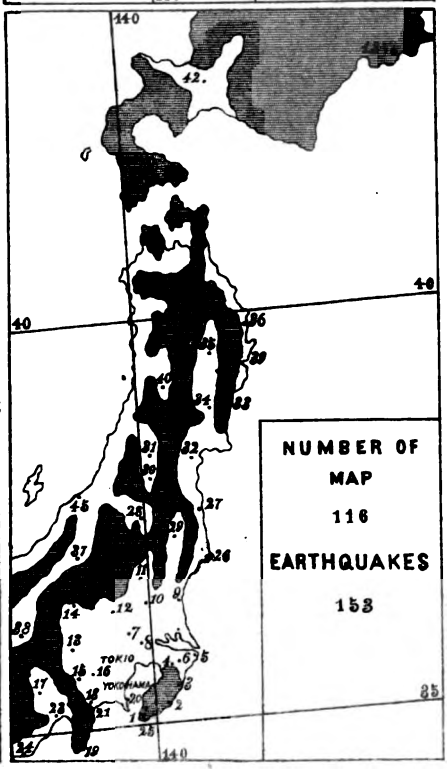

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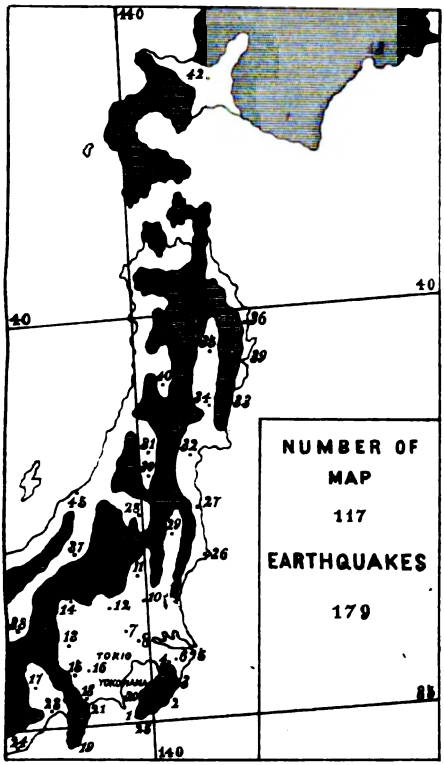

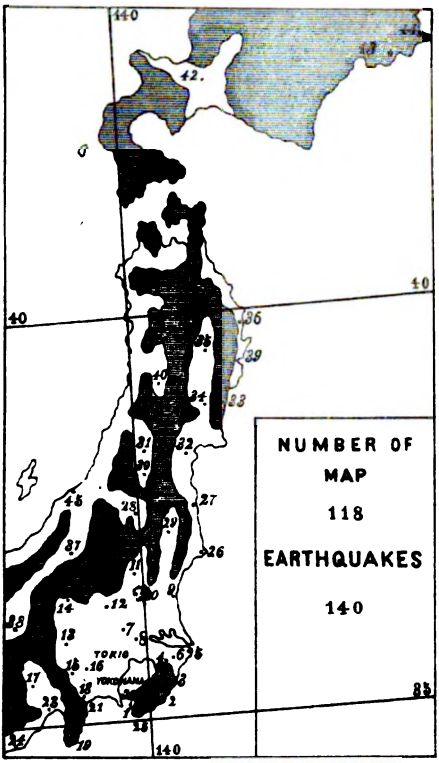

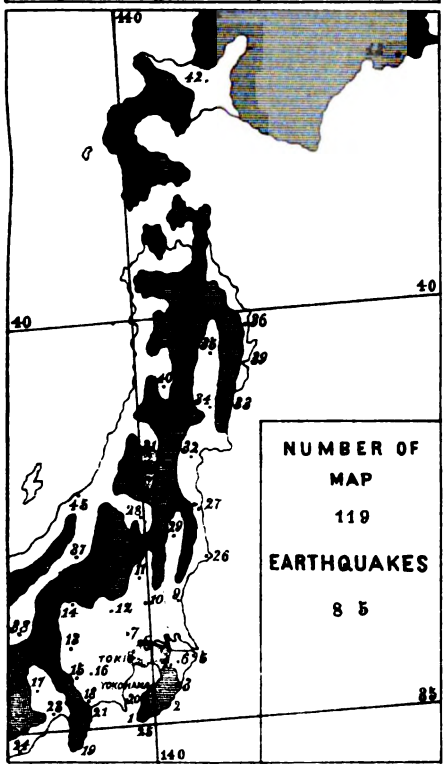

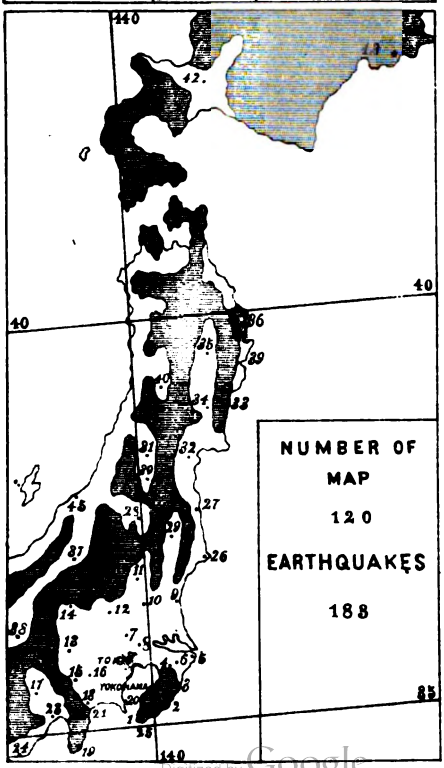

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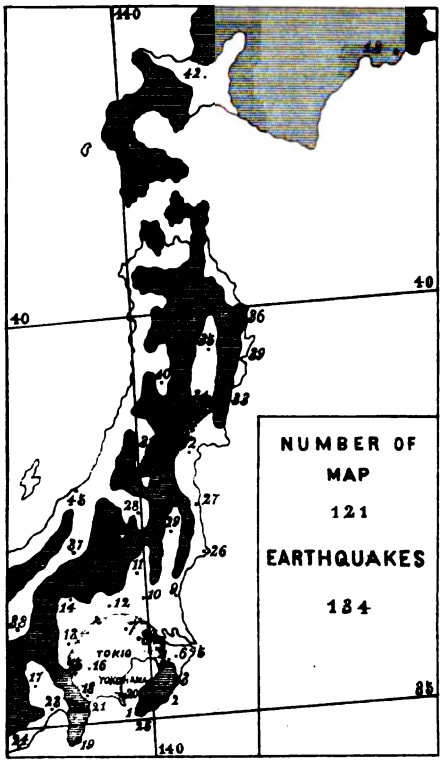

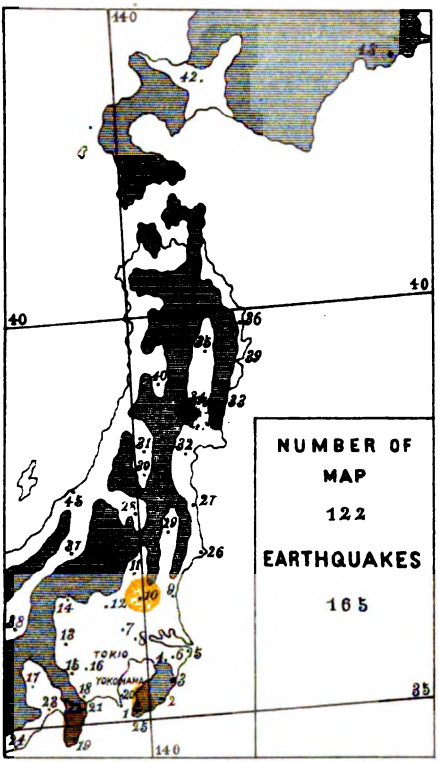

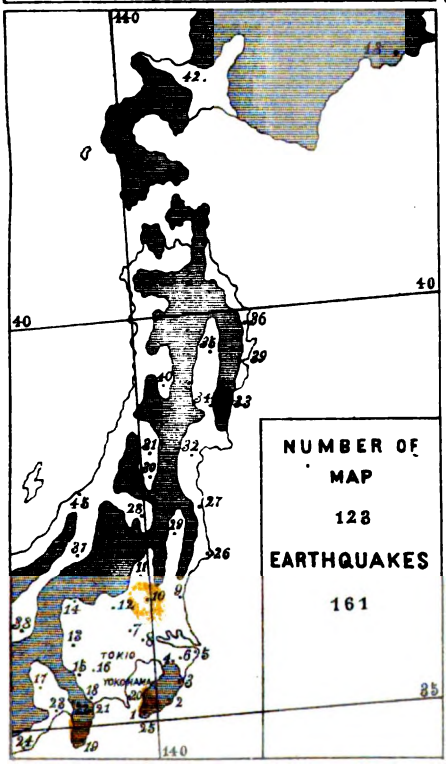

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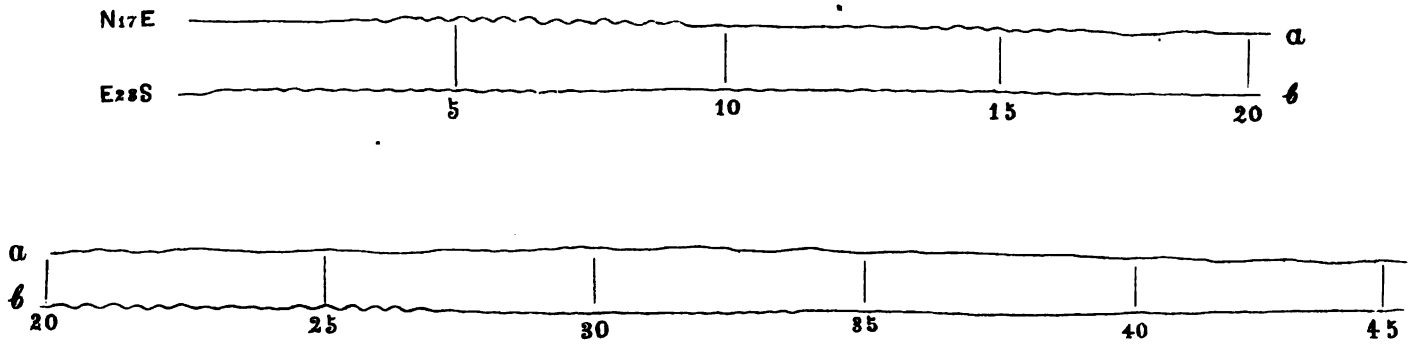

FIG 1 (Conical Pendulums.)

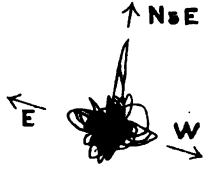

FIG 2

FIG 3

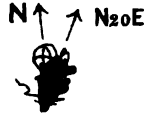

FIG 4

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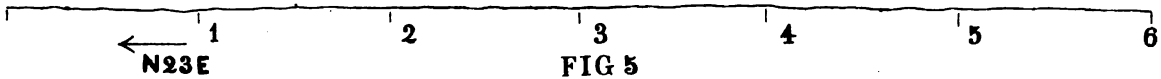

FIG 5

(Bracket. E23S motion.)

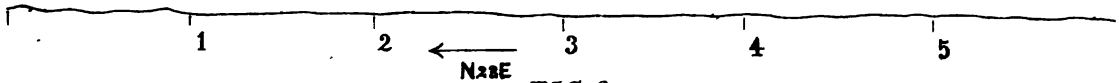

FIG 6

(Double Bracket.)

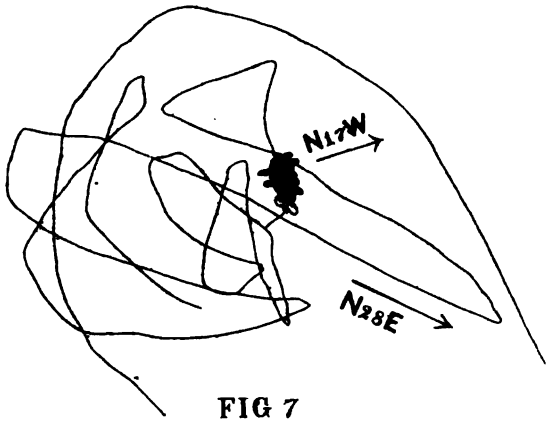

FIG 7

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FIG 8

FIG 9

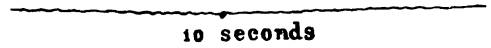

FIG 10

(Conical Pendulums. N78W)

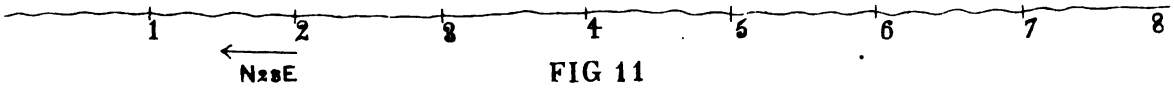

FIG 11

(Double Bracket)

FIG 12

FIG 13

FIG 14

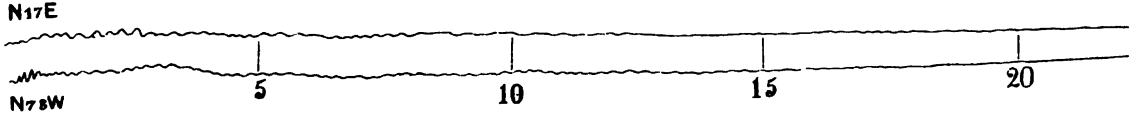

FIG 15

(Conical Pendulums.)

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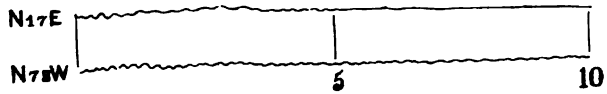

FIG 16
(Conical Pendulums.)

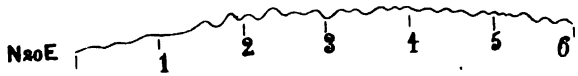

FIG 17
(Rolling Cylinders.)

FIG 18

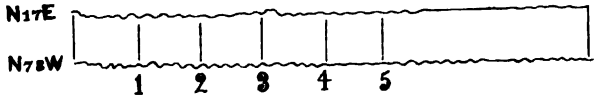

FIG 19
(Conical Pendulums.)

FIG 20

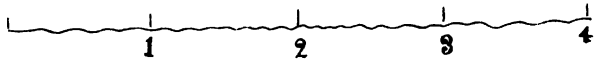

FIG 21
(Vertical Spring.)

FIG 22

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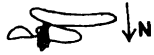

FIG 23

FIG 24

FIG 25

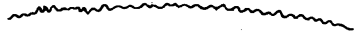

FIG 26
(Rolling Cylinders.)

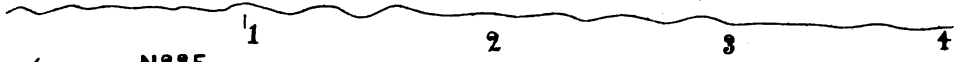

FIG 27
(Double Bracket.)

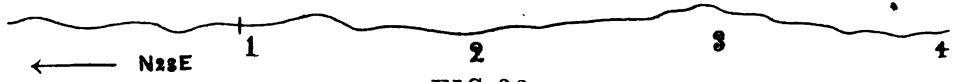

FIG 28
(Pendulum.)

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FIG 29

FIG 30

FIG 31

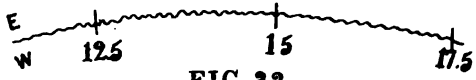

FIG 32

(Bracket Seismograph.)

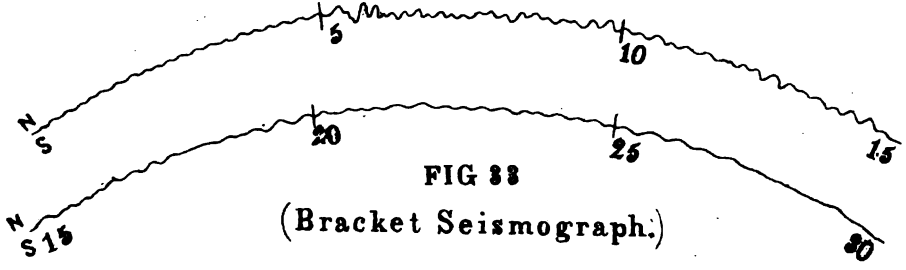

FIG 33

(Bracket Seismograph.)

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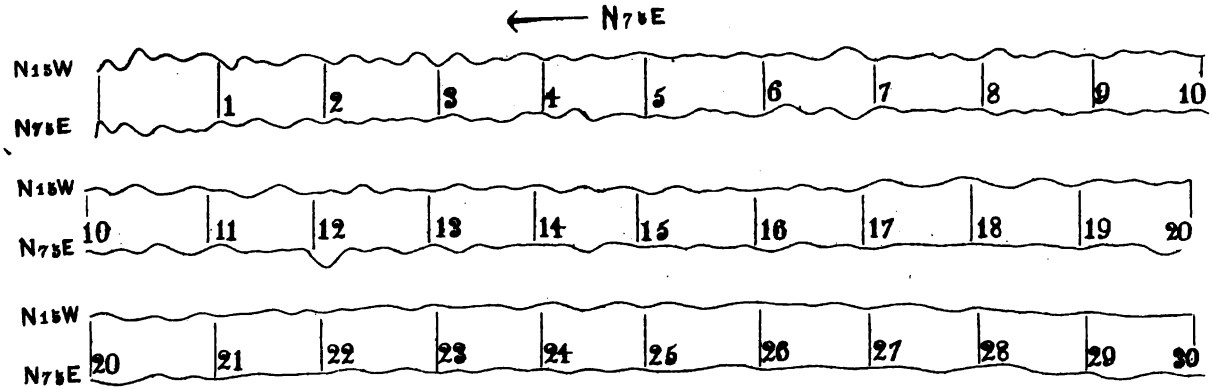

FIG 34
(Bracket Seismograph.)

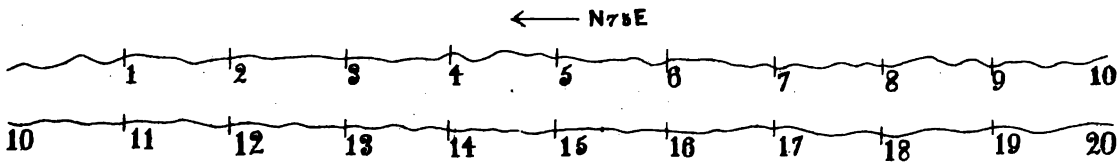

FIG 35
(Pendulum Seismograph.)

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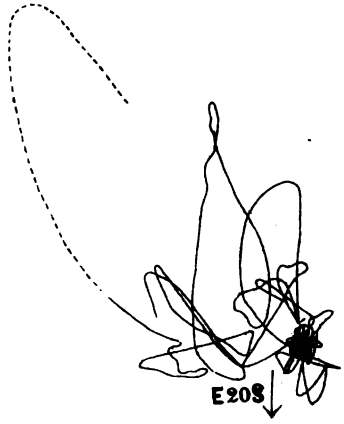

FIG 36

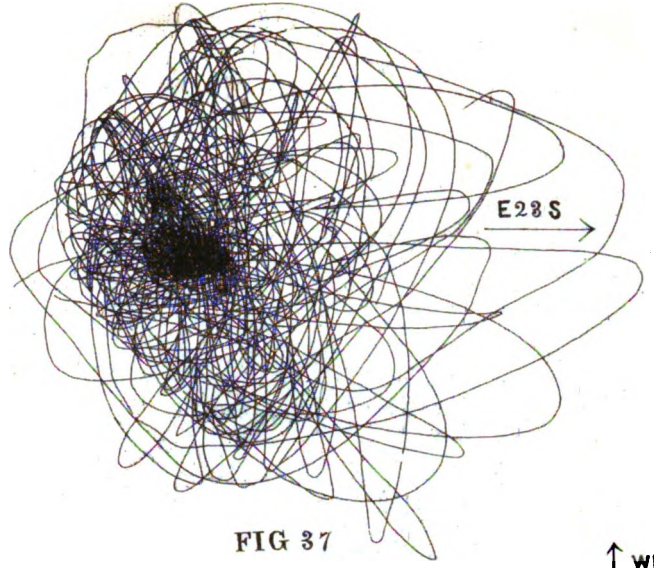

FIG 37

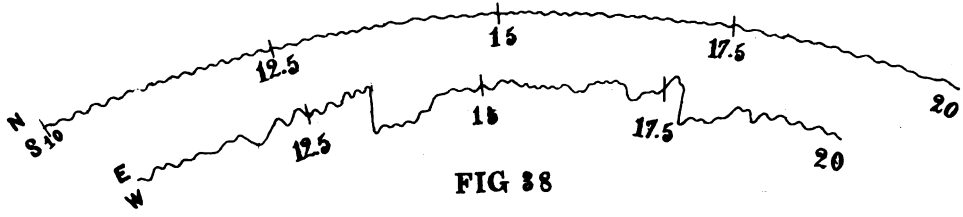

FIG 38

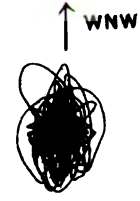

FIG 39

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FIG 41

FIG 42

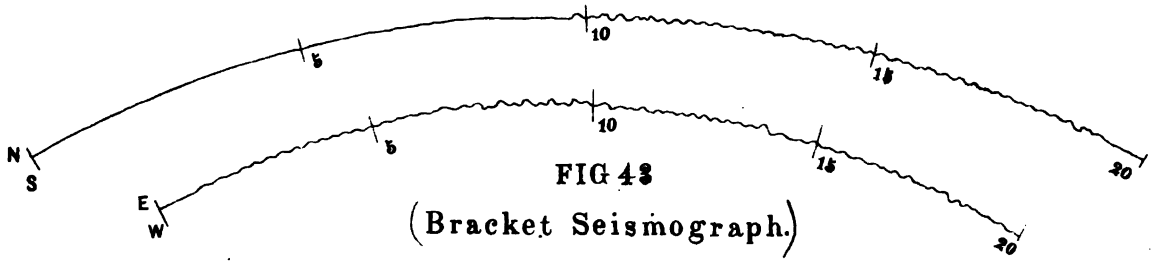

FIG 43
(Bracket Seismograph.)

FIG 44

FIG 45

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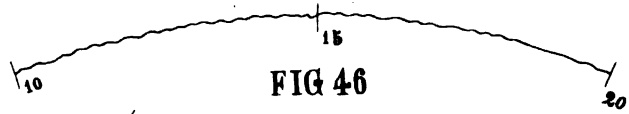

FIG 46

(Bracket Seismograph.)

S28E

FIG 47

FIG 48

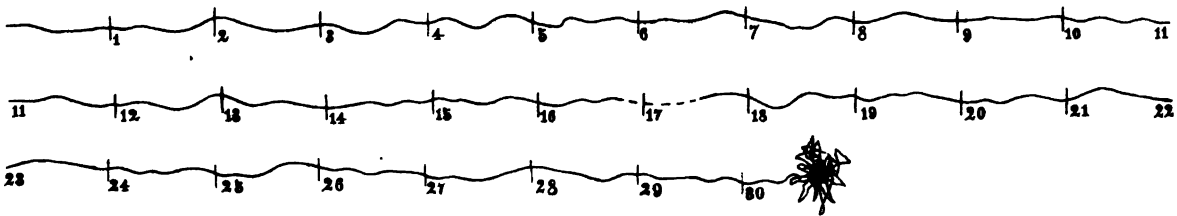

FIG 49

(Pendulum Seismograph.)

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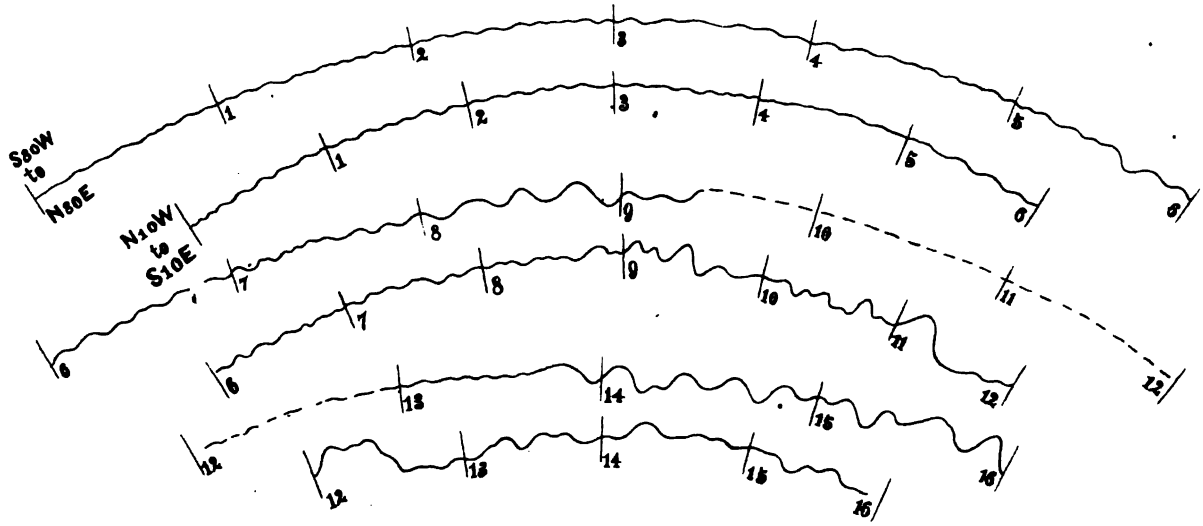

FIG 50

(Bracket Seismograph.)

FIG 51

FIG 52

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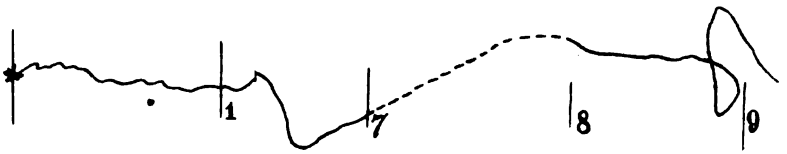

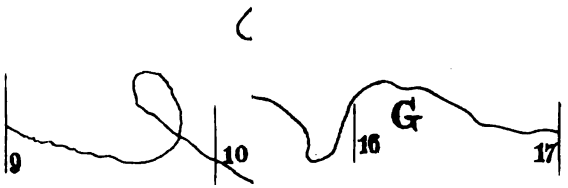

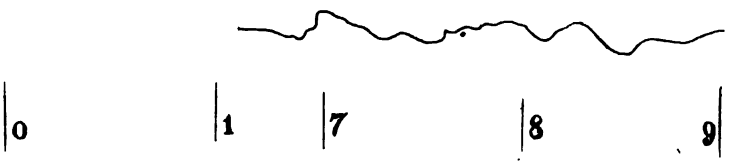

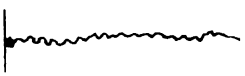

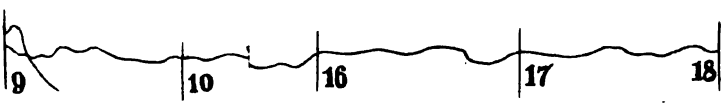

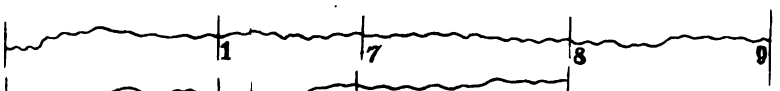

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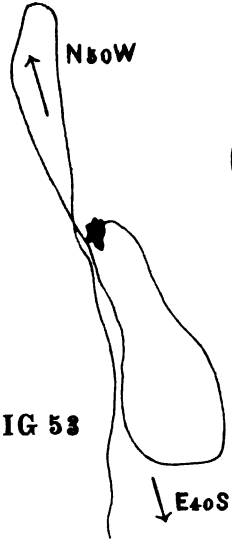

FIG 53

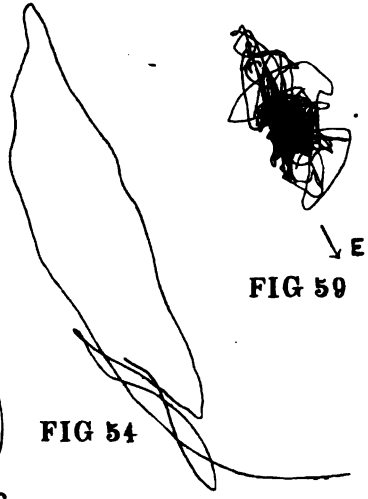

FIG 54

FIG 59

FIG 60

FIG 61

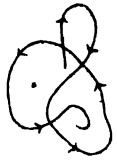

FIG 62

FIG 63

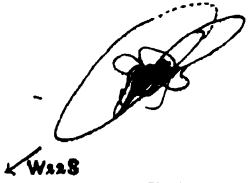

FIG 64
(Rolling Sphere.)

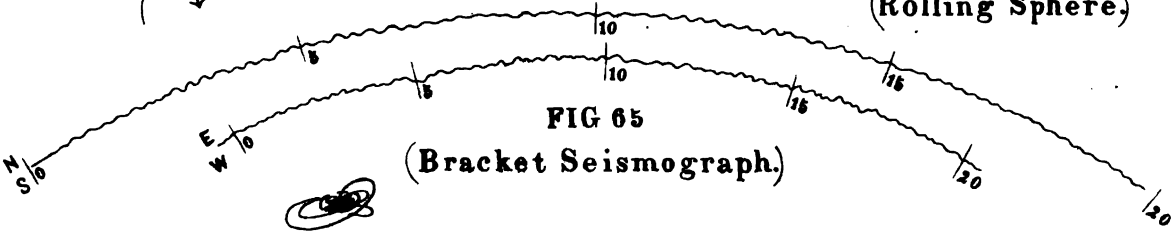

FIG 65
(Bracket Seismograph.)

FIG 66
(Rolling Sphere.)

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J. MILNE,—*A visit to the Volcano of Oshima.*

DEC. II. VOL. V. No. 8. ALSO DEC. II. VI. No. 11.

J. MILNE,—*On the form of Volcanoes.*

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DEC. II. VOL. VI. No. 8.

J. MILNE,—*A cruise among the Volcanoes of the Kurile Islands.*

DEC. II. VOL. VII. No. III.

J. MILNE,—*Note on the cooling of the Earth.*

DEC. II. VOL. VII. No. IV.

J. MILNE,—*Note on the Geographical distribution of Volcanoes.*

MISCELLANEOUS PUBLICATIONS.

J. MILNE AND T. GRAY,—*On Seismic experiments. Trans: Royal Society. 1882.*

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J. MILNE AND T. GRAY,—*On the Elasticity and Strength Constants of certain rocks. Quart: Jour: Geolog: Soc: 1882.*

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BENJAMIN SMITH LYMAN,—*Reports of the Geological Survey of Hokkaido.*

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EDMUND NAUMANN,—*Die Vulcaninsel Ooshima and ihre jüngste Eruption. Zeitschrift der Deutschen Geologischen Gesellschaft, 1877.*

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J. MILNE,—*Earth Movement. The Times Oct. 11. 1882.*
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J. MILNE,—*Earthquakes and Buildings. Nature Vol. XIX. p. 290.*
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T. GRAY,—*On Instruments for recording Earthquake motion. Phil: Mag., 1881.*
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T. H. STREETS,—*A fours years record of Earthquakes in Japan, studied in relation to the weather and Seasons. American Jour. of Science. May. 1883.*
J. MILNE,—*Recherches sur les tremblements de terre au Japon. (Congrès Géologique de Berlin) Imprimeris de L'echo du Japon. Yokohama. 1884.*

In addition to the above, numerous notes relating to the Earthquakes and Volcanoes of Japan may be found by reference to the index columms of Nature, and to the files of the Japan Gazette, the Japan Herald and the Japan Mail.

Vol. III. of the Trans: of the Seis: Soc: of Japan contains a list of 64 works in Japanese relating to the Earthquakes of Japan.

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TRANSACTIONS

OF THE

SEISMOLOGICAL SOCIETY OF JAPAN.

VOL. VIII.

1885.

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SEISMIC EXPERIMENTS

BY

JOHN MILNE

Imperial College of Engineering, Tokio, Japan.

[Read Oct. 13. and Nov. 12. 1884]

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6. Fifth series of Experiments. Meteorological Department. March 1882. *Velocity of different kinds of vibrations. Vertical motion. Synchronism of neighbouring points of ground. Production of earth currents.*

7. Sixth series of Experiments. Meteorological Department. May 1882. *Experiments on Velocity.*

8. Seventh series of Experiments. Meteorological Department. May 1882. *Experiments on projection and overturning.*

9. Eighth series of Experiments. Meteorological Department. July 1883. *Different methods of determining intensity.*

10. Ninth series of Experiments. Imperial College of Engineering. 1884. *Labratory experiments to investigate methods of interpreting diagrams and the relation between diagrams and the overturning and projecting power of earthquakes.*

11. Tenth series of Experiments (in conjunction with Mr. T. Gray) Imperial College of Engineering. 1881. *On the elastic moduli of certain rocks.*

12. *General results, indexed for reference to the experiments by which they were obtained.*

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INTRODUCTION.

The following paper is an account of a large number of experiments made at different times and in different places for the purpose of investigating phenomena connected with earth vibrations. The idea of making such experiments suggested itself to me in 1880.

In 1881 in conjunction with Mr. T. Gray formerly one of my colleagues at the Imperial college of Engineering, I commenced these experiments at the Engineering Works at Akabane in Tokio. Subsequently to this, eight other sets of experiments were undertaken the last being made on July 6 1883.

The earth vibrations which were studied were produced either by some explosive like dynamite or by allowing a heavy weight to fall from height. Each set of experiments involved several weeks preparation, and in some cases extended over several days. Among the chief difficulties which had to be overcome in connection with the experiments may be mentioned, that of obtaining dynamite from the government stores, its transportation, its storage, the difficulties of obtaining a piece of ground on which to experiment, manufacturing the necessary instruments, obtaining telegraph wire and its erection between the observing stations, the arrangement of firing apparatus, the manufacture of electric fuzes, the anxiety lest accidents should occur, putting down bore holes in which to fire dynamite, training assistants, the difficulties of contending against bad weather which had often to be encountered on days for which permission had been granted.

For the use of ground where the experiments were performed and for the loan of tents to cover the instruments at the different observing stations and for a body of attentive servants, my thanks are due to His Excellency General Yamada late Minister of the Interior, and Mr. Arai Ikunosuke Director of the Meteorological Department. For the loan of telegraph wire, firing apparatus and other instruments, I tender my thanks to the director and officers of the Public

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Works Department, the Department of Imperial Telegraphs, the Naval and War Departments, to the officers of the Imperial College of Engineering and the Engineering works at Akabane. For much personal assistance I have to thank Mr. Denys Larrieu and Mr. John Reid who supplied me with dynamite, my colleagues at the Imperial College of Engineering, and many other residents in Tokio who from time to time came to witness the experiments.

In commencing my experiments the only data which I had for guidance were the results obtained by the late Mr. Robert Mallet and General H. L. Abbot. These gentlemen however only experimented on the velocity with which earth vibrations were propagated. In taking diagrams of earth motion I was therefore entering upon new ground and, as might be anticipated, continually encountered unexpected results. Sometimes for instance it was found that the instruments which were employed would require modification before satisfactory records could be obtained, at other times the records which were obtained gave indications of new lines of investigation to carry out which a new instalment of apparatus would be required, &c. For reasons like these many of the results given in the following pages can only be regarded as provisional, as for example those which relate to the velocities of normal and transverse vibrations. Should opportunity present itself for continuing those investigations there is no doubt that much of what is here recorded might be repeated, and by taking advantage of my experience more accurate results might be obtained.

As examples of investigations which have yet to be undertaken I may mention the following.

1. An accurate determination of the rate at which the velocity of transit decreases as a disturbance radiates from its origin.
2. The relationship between the velocity of transit and the intensity of the initial disturbance.
3. The determination of the rate at which the intensity of a disturbance decreases as measured at different distances from the origin. This might perhaps lead to

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the construction of a curve of intensities from which the absolute intensity of the initial disturbance could be learnt.

4. A more complete investigation of vertial motion and free surface waves.
5. An investigation of the inward motion of shocks. In my experiments the movement of the ground from its neutral position *in* towards the origin of the disturbance has been performed so rapidly that I have been unable with the instruments at my disposal to accuratly measure its velocity. As this is probably the most destructive element of motion its investigation is exceedingly important.
6. Farther investigations on the relationship between earthquake diagrams and the overturning and projecting of various bodies.
7. A repetition of these and all other experiments on different kinds of ground.

&c. &c. &c.

Although in these and other respects my investigations are imperfect, many facts relating to the nature of earth motion have been collected. One striking result is the great differences between the results of observation and what would have been anticipated from theoretical investigations where it was assumed that the ground had behaved as a perfectly elastic body.

I may here call the attention of those who have occasion to refer to these experiments that with the exception of the tenth set, the remainder succeed each other in the order in which they were performed. This order becomes more systematic and the results which have been obtained appear more nearly consequential in their relation to each other, if the ninth set of experiments are placed before the fourth set. They ought certainly to be read before the seventh set. At the end of this paper I have summed up the different results which have been reached, indicating the experiment or experiments where the data on which such results are founded may be found. This has necessarily led to repetition

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but it has resulted in a systematic and convenient arrangement of results. In conclusion I may state that the nature of the experiments which I record are such that it is hardly just to expect them to be carried out satisfactorily by an individual. The trouble, the expense, the danger and I may add the magnitude of the arrangements which they involve make them fitter undertakings for an army corps rarther than for a private person. In addition to the field experiments, I also give an account of several laboratory experiments made for the purpose of determining the elastic moduli of rocks, the projection of bodies from springs &c. all of which it will be seen are fairly included in the title of this paper.

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I. SERIES OF EXPERIMENTS.

The first experiments were made in January and Febuary 1881 by Mr. Gray and myself at the Akabane Engineering works in Tokio. An account of these experiments has been published in the Philosophical Transactions of the Royal Society. Part III. 1882.

The vibrations were produced by the fall of a ball weighing 1710 lbs, from varying heights up to 35 feet. In consequence of the blow which the ball gave, the surrounding ground, which was a hardened mud, was caused to vibrate for a distance of about 300 feet. A plan of the ground is shown in Fig. 1. The methods of observing the vibrations were various. A simple means of determining the relative amount of motion experienced at different stations was the observation of the number of seconds that the same quantity of mercury contained in similar vessels continued to move. These observations required a number of observers who, to equalize errors of observation, were interchanged between the different stations for each new experiment. In addition to simple contrivances like these, seismographs which gave a record of their movements on smoked glass plates were employed, as for instances Bracket seismographs similar to those employed by Prof: Ewing, Conical Pendulum seismographs, Rolling sphere seismographs &c. To record vertical motion, the can of liquid with a flexible bottom and Gray's vertical lever spring seismograph were employed. Descriptions of these instruments may be found in the Transactions of the Seismological Society of Japan.

The smoked glass plates on which the instruments wrote, were sometimes stationary and at other times by means of suitable contrivances they were drawn along horizontally beneath the writing indices. By means of electrical connections between the points of observation and a pendulum swinging across a cup of mercury, time ticks were made on the various plates. This furnished means to determine the velocity with which a disturbance was propagated, and facilitated exact comparisons being made between diagrams

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obtained at different stations. Independently of the time occupied in making the necessary preparations, the experiments extended over nine days, the ball being dropped four or five times each day.

The more important results which were obtained were as follows.

1. A partial determination of the effect of hills and excavations (like a deep pond) upon the transmission of vibrations. Small hills had but little effect in stopping vibrations, but a pond to a certain extent cut off both normal and transverse motion.
2. A complete graphical separation of normal from transverse vibrations. The existence of these two kinds of vibration was first observed in diagrams like Figs 2, 3 and 4 taken by means of a rolling sphere seismograph on a stationary smoked glass plate. At the commencement the needle of the pointer was resting near C. It first moved to A, then to B and back towards C at or about which point its motion was suddenly deflected. The direction in which the disturbance came is shown by the arrow. A more complete separation of the normal and transverse movement was obtained by placing two bracket seismographs at right angles, so that one recorded all motion in the direction of propagation and the other all motion at right angles to such a direction. It was observed that the former of the two seismographs invariably commenced to write its record before the latter.
3. A determination of the relative amplitudes of the normal and transverse motions as observed at points differently situated with regard to the origin of the shock. Near the origin the normal motion was much the greater, but in proceeding outwards from the origin the normal motion diminished the more rapidly of the two. Roughly speaking the amplitude of the normal vibrations was inversely as the distance from the origin.
4. There were usually about six vibrations per second. The normal vibrations had the quicker period.

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5. The average velocity of the normal vibrations was 438 feet per second whilst that of the transversal movements was only 357 feet.
6. At a distant station (250 feet) four or five dissimilar vibrations would be recorded, and then the same four or five vibrations would be repeated in the same order as those first recorded.

II. SERIES OF EXPERIMENTS.

These experiments were made by myself and Mr. T. Gray at Yokosuka, a naval dockyard about 20 miles distant from Tokio. The ground was a horizontally stratified soft clay rock. The vibrations were produced by dropping a heavy weight from a height of about 40 feet. Although the weight was heavier than the one previously employed, on account of the nature of the rocks we found it impossible to create a disturbance which could be recorded at a distance greater than 20 feet, and even then the vibrations which were recorded had amplitudes too small to admit of satisfactory analysis.

For these reasons, after much time had been spent in making instruments, transporting them to Yokosuka, and obtaining the necessary permission to work, the experiments had to be abandoned. The negative result which was obtained is however worthy of record.

III. SERIES OF EXPERIMENTS.

In this series of experiments which were made in December 1881 the disturbances were created by the explosion of dynamite and other substances. Although many valuable results were obtained, owing to the heavy fall of snow which took place on the days for which permission had been granted to perform the experiments, the large number of visitors who assembled, the fact that the instruments which were employed had been hurriedly constructed and for other reasons, many of the diagrams which were obtained were imperfect. In consequence of these experiments however, experience was gained in

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properly proportioning charges of dynamite and in the general working of the apparatus which led to the satisfactory results obtained on subsequent occasions.

For the dynamite which was used and also for considerable assistance I have to thank Mr. John Reid agent of Nobel & Co. The charges employed varied from a few ounzes to 2 or 3 lbs. They were fired near the place where in the first set of experiments the ball fell. Some of the charges were fired on the surface of the ground, some in the neighbouring pond, whilst others were exploded in bore holes from 3 to 12 feet in depth and 3in in diameter.

The effect of an explosion in a bore hole was to produce a large cavity 4 or 5 feet in diameter at the top, and opening out downwards to a pear shaped form, the diameter below being double that at the top. For a given charge the greatest effect was produced when it was exploded in the neighbouring pond. The great advantage gained by using dynamite may be judged of from the fact, that the maximum displacement of an earth particle 50 feet distant from the place where the ball fell, was hardly more than $\frac{1}{6}$ of that produced by 2 lbs of dynamite in a six foot bore hole acting at the same distance.

The charges were fired by means of a small electro-dynamo machine and tension fuses.

The instruments employed were three pendulum seismographs and three bracket seismographs. The former wrote their record on stationary plates whilst the latter wrote on plates which at the time of an explosion were drawn horizontally by means of falling weights beneath the recording pointers. There were three observing stations on the line AD Fig. 1. at distances from the scene of explosion of 50, 150 and 250 feet respectively. At each of these stations there was one of the above instruments. All the stations were electrically connected so that the swings of a small pendulum passing through a cup of mercury could be recorded on each of the moving record receivers.

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The results of the experiments were as follows:—

1. EXPERIMENT.

Six oz. of gelatine (a new nitroglycerine compound) was exploded in a six foot bore hole. No effect was produced even at the 50 foot station.

2. EXPERIMENT.

6 oz. of gelatine together with 18 oz. of dynamite were exploded in a 7ft bore hole.

PENDULUM SEISMOGRAPH.

	Maximum Amplitude		
	Normal	Transverse	Remarks
At 50 ft. Station Fig. 5	3mm	.7mm	Three normal movements.
At 150 ft. Station Fig. 6	1.2	0	,, ,, ,,

3. EXPERIMENT.

18 oz. of dynamite exploded on the surface of the ground.

PENDULUM SEISMOGRAPH.

At 50 ft. Station. A maximum amplitude of .4mm at an angle of about 45° to true normal direction. Three or four complete vibrations.

BRACKET SEISMOGRAPH.

	Maximum Amplitude		
	Normal	Transverse	Remarks
At 50 ft. Station	.01mm	.01mm	The first motion compression.
At 150 ft. ,,	slight	slight	Two or three small ripples.

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4. EXPERIMENT.

18 oz. dynamite fired in the pond near A. Fig. 1. The instruments being in the old position along the line A D were therefore not in one line with the origin of the disturbance.

PENDULUM SEISMOGRAPH.

At 50 ft. Station. A decided normal motion of .6^{mm}. The transverse motion was slight.

BRACKET SEISMOGRAPH.

	Maximum Amplitude		
	Normal	Transverse	Remarks
At 50 ft. Station	not well recorded	.5^{mm}	Altogether 11 vibrations.
At 150 ft. ,,	.25	.25	,, ,, ,,

The above movements are on account of the position of the explosion only approximately normal and transverse. The normal at the 150 ft. Station commenced as two slight ripples slightly before the transverse. The first movement was *in* towards the origin. The maximum movements consist of three large waves. The transverse movement commences irregularly. Fig. 7.

5. EXPERIMENT.

About 12 oz. dynamite were exploded in the pond near A.

PENDULUM SEISMOGRAPH.

At 50 ft. Station. Maximum amplitude of .4^{mm} intermediate to normal and transverse directions. (Record not good).

At 150 ft. Station. Maximum amplitude in a normal direction of nearly .4^{mm}. (Record not good).

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BRACKET SEISMOGRAPH.

	Maximum Amplitude		
	Normal	Transverse	Remarks
At 50 ft. Station	.21^{mm}	not recorded	8 vibrations per sec.
At 150 ft. ,,	not well recorded	.14^{mm}	,, ,, ,, ,,

At the 50 ft. Station motion commenced with 2 small vibrations, the first movement being *inwards* towards the origin. The maximum movement is the fourth vibration. Motion continued for about half a second.

6. EXPERIMENT.

The ball (1710 lbs) fell 35 feet.

PENDULUM SEISMOGRAPH.

At the 50 ft. Station, there was motion in a normal direction of .7^{mm} and a motion in a transverse direction of .4^{mm}. The movements in the two directions are not distinctly separated.

At the 150 ft. Station, the motion in a normal direction was .3^{mm}.

BRACKET SEISMOGRAPH.

At the 150 ft. Station. Both the normal and transverse motions were very slight.

7. EXPERIMENT.

The ball (1710 lbs) fell 35 feet.

PENDULUM SEISMOGRAPH.

At the 50 ft. Station. Maximum amplitude .6^{mm}.

BRACKET SEISMOGRAPH.

At the 150 ft. Station. The normal motion has a maximum amplitude of .5^{mm} and a duration of about 1^{sec}. The first

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movement was outwards. There are 8 or 9 vibrations per second. The transverse motion has a maximum amplitude of .14^{mm}.

8. Experiment.

2½ lbs of dynamite exploded in the pond.

PENDULUM SEISMOGRAPH.

	Maximum amplitude		Remarks
	Normal	Transverse	
At 50 ft. Station	2^{mm}	slight	Three or four decided motions.
At 150 ft. ,,	.6^{mm}	,,	

BRACKET SEISMOGRAPH.

	Maximum amplitude		Frequency of vibrations per sec.	
	Normal	Transverse	Normal	Transverse
At 50 ft. Station	.42^{mm}	.57^{mm}	4 or 5	3 or 4
At 150 ft. ,,	not taken	.28	not recorded	3 or 4
At 250 ft. ,,	.14	.14	too small to measure	

The above directions are only approximately normal and transverse. At the 50 ft. at 250 ft. stations the first motions were distinctly those of compression or in a direction outwards from the origin. At the 50 ft. station the first two normal motions have ripples superimposed upon them. Fig. 8. The duration of motion is 2½ sec. The duration of the transverse motion is 4 sec. The first vibrations have ripples superimposed on them. The duration at the 150 ft. station of the transverse component is 1.5 sec. At the 250 ft. station the motion although decided is irregular. The transverse component reaches its maximum after the normal has become very small.

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9. EXPERIMENT.

3½ lbs of dynamite exploded in a 9 ft. bore hole. At the distance of 100 feet the motion felt like that of a small earthquake.

PENDULUM SEISMOGRAPH.

	Max. amplitude	Remarks
At 50 ft. Station	about 5^{mm}	The pointer was driven off the plate
At 150 ft. ,,	1.7^{mm}	In a direction intermediate to Normal and Transverse

BRACKET SEISMOGRAPH.

	Maximum amplitude		Frequency of vibrations per sec.	
	Normal	Transverse	Normal	Transverse
At 50 ft. Station	7^{mm}	not recorded	5 or 6	not recorded
At 150 ft. ,,	$.56^{mm}$	$.6^{mm}$	5	5
At 250 ft. ,,	$.4^{mm}$	$.4^{mm}$	5 or 6	4 or 5

In all cases as the motion dies out the frequency of waves decreases to about 3 per second.

At the 150 ft. station normal motion commences with a movement of $.28^{mm}$ inwards. This is followed by an outward motion of $.36^{mm}$ which is succeeded by three large vibrations each about $.56^{mm}$. Transverse motion commences with a small movement of $.07^{mm}$ which is followed by two large motions each $.64^{mm}$.

At the 250 ft. station the normal motion commences outwards as is always the case at this station. The 3rd, 4th and 5th movements are the largest. The transverse motion commences gently.

At the 150 ft. station normal motion commences to be recorded .26 to .29 seconds before the transverse motion.

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10. EEPERIMENT.

2 lbs of dynamite exploded in hole 5 ft. deep.

PENDULUM SEISMOGRAPH.

	Maximum amplitude		Remarks
	Normal	Transverse	
At 50 ft. Station	3.3^{mm}	.7^{mm}	There are 3 or 4 decided normal motions. The transverse motions are oblique to them.
At 150 ft. ,,	1^{mm}	.7^{mm}	These motions are at right angles to each other but each is inclined at 45° to a true normal direction.

BRACKET SEISMOGRAPH.

	Maximum amplitude		Frequency of vibrations per sec.	
	Normal	Transverse	Normal	Transverse
At 50 ft. Station	2.1^{mm}	1^{mm}	7 or 8	7 or 8
At 150 ft. ,,	.35	.35	8	6
At 250 ft. ,,	.21	.25	—	—

At the 50 ft. station the normal motion commenced with .5^{mm} of motion outwards followed by 1.6^{mm} motion inwards. After this come 4 of the largest waves. The motion then quickly dies out. The duration is 1½ seconds. Fig. 9.

The transverse motion consists of 4 almost equal vibrations described in .33 sec.

At the 150 ft. station motion commenced by a very slight inward motion after which the motion is .21^{mm} outwards. After 3 large vibrations which follow, the motion rapidly dies out. The transverse motion commences with 2 gentle vibrations each about .05^{mm}. From the appearance of the diagram it is evident that the period of the normal motion is shorter than that of the transverse motion.

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At the 250 ft. Station 6 large normal vibrations are distinctly visible. The transverse component which commences as a ripple is slightly larger than the normal motion.

At the 50 ft. Station both normal and transverse motion commence at the same instant.

At the 150 ft. Station the normal motion is .19 to .24 sec. ahead of the transverse movement.

The velocity of the normal motion between the 50 ft. and 150 ft. Stations lies between 265 feet and 294 feet per second. The velocity of the transverse motion between the same stations was 176 feet per second.

11. EXPERIMENTS.

The Ball (1710 lbs) fell 35 feet.

PENDULUM SEISMOGRAPH.

At the 50 ft. Station the maximum amplitude was $.7^{mm}$ The direction of motion was at 45° to the true normal direction. The disturbance commenced with a slight normal motion.

BRACKET SEISMOGRAPH.

At the 50 ft. Station the maximum amplitude of the normal motion is $.21^{mm}$. The first motion was outwards. The general appearance of this diagram is very like that of experiment 10, only smaller. First there are two large waves after which the motion rapidly dies out. The duration of the disturbance is $.5^{sec}$.

The transverse motion is also like that of experiment 10, only differing from it in being smaller Fig. 10.

At the 150 ft. Station. The normal motion is only represented by a straight line. The transverse motion shews 2 or 3 small flat ripples.

IV. SERIES OF EXPERIMENTS.

These experiments were made on December 26th 1881 in a field opposite the Kobusho (Public Works Department).

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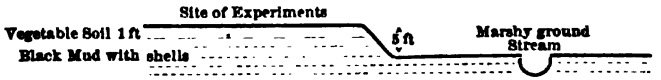
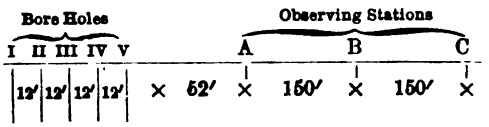
On the surface, the ground was dry but a few feet down it was very wet. A cross section on the line of operations is shown in the accompanying figure.



A section along the line of operations is follows.



The Bore Holes I II III IV and V were from 8 to 9 feet in depth. They were naturally filled with water to within 3 feet of the surface. This water together with a quantity of loose earth which was poured into the holes about the charges of gun powder and dynamite which were exploded, acted as tamping. The distances that A B & C were from the origins of the successive explosions were as follows,

	A	B	C
For the 1st Explosion	100 ft	250 ft	400 ft
„ „ 2nd „	88 „	238 „	388 „
„ „ 3rd „	76 „	226 „	376 „
„ „ 4th „	64 „	214 „	364 „

At A B and C bracket seismographs were employed. The multiplication of these instruments was 12. At B, Gray's lever spring seismograph for vertical motion wrote a record side by side with that of the bracket seismograph. At A and B pendulum seismographs with a multiplication of 10 were placed.

The indices of the bracket seismographs rested on the surface of a smoked glass plate which at the time of the shock was moved horizontally in the same manner as in the experiments at Akabane. The electrical arrangements by which the record receivers were set in motion and as they moved had time intervals recorded on their surface, will be understood from the following diagram.

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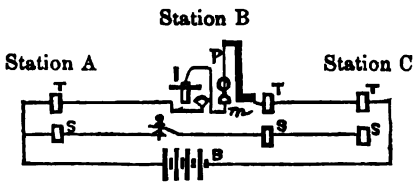
T and S in the diagram represent two electro-magnets at each of the three stations. T is a magnet which deflects a small pointer on the moving plate to mark time intervals whilst S is a magnet which withdraws a catch and sets the record receiving carriages free.

By closing the key 2 and completing the circuit 2 S B S S the carriages are set free. By closing the key 1 and allowing the pendulum P to swing through the mercury *m*, the circuit *m* T B T T is continually opened and shut. With each swing of the pendulum the magnets T deflect a lever and record a time interval on the moving plates.

The operations were as follows. First the carriages were set in motion by means of key 2. Next key 1 was closed and time ticks were recorded on the moving plate. Immediately after this by means of a separate battery and an Induction coil the charge was exploded. Some 10 seconds later the motion of the record receivers was stopped, and remained at rest until a second charge had been prepared. In this manner experiment succeeded experiment without any alteration in the adjustment of the various instruments.



1. Experiment.

Three lbs of dynamite exploded in bore hole Number I.

PENDULUM SEISMOGRAPH.

	Maximum extent of motion		
	Normal	Transverse	Remarks
At Station A (100 ft.)	2.1^{mm}	.5^{mm}	
At Station B (250 ft.)	1.1^{mm}	.3^{mm}	The transverse was irregular.

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BRACKET SEISMOGRAPH. (Fig. I. last plate.)

	Maximum extent of motion		Maximum frequency of vibrations	
	Normal	Transverse	Normal	Transverse
At Station A (100 ft.)	2.1^{mm}	.53^{mm}	4 per sec.	4.5 per sec.
At Station B (250 ft.)	.5^{mm}	.23^{mm}	3 ,, ,,	3 ,, ,,
At Station C (400 ft.)	.15^{mm}	.1^{mm}		

At Station A. The normal disturbance commenced by a slight motion outwards. The largest wave is the third one from the commencement. On the heads of each of the large waves a small ripple is superimposed. The amplitude of motion is greatest on the side of the origin or inwards. Motion extends over 3. 5 seconds, in which period there are 10 vibrations. At the end of the disturbance there are only 2 complete waves per second.

The transverse motion rapidly dies out after the second vibration which is the largest. At the end of the disturbance there are only 2 vibrations per second. Altogether there are 11 vibrations in 4 seconds.

At Station B. The normal motion commences as three gentle ripples, the first being in the direction of compression or outwards. After that come three large but slow vibrations.

The Transverse motion commences with two gentle vibrations.

At Station C. The first normal motion is inwards. There is no marked distinction between the different waves like that recorded at Station A.

The transverse motion has about the same period as the normal.

Vertical motion. This was recorded at station B. It apparently commences before the normal motion. At the commencement there are 6 waves per second but at the end only 2 per second. The quickly described waves have an amplitude of .16^{mm} whilst those which were slower have an amplitude of .44^{mm}.

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If we take the *smallest* of these measurements and combine it with the *largest* normal motion at this station ($.46^{mm}$) to obtain the tangent of the angle of emergence, we can calculate the least possible depth of the origin. The depth so calculated is 86.75 feet. We however know the depth to have been about 8 feet. The conclusion arrived at is therefore that the vertical motion is not due to a direct shock but to a surface wave. Farther it may be added that persons standing near Station B at the time of the explosion could feel the ground rising and falling as if such waves were passing beneath their feet.

2. EXPERIMENT.

Three pounds of dynamite exploded in bore hole Number II.

PENDULUM SEISMOGRAPH.

Maximum extent of motion.

At Station A 88 ft.	Motion oblique to normal and transverse 2.6^{mm}
At Station B 238 ft.	Normal 1.3^{mm} Transverse $.4^{mm}$. No distinct separation of normal and transverse.

BRACKET SEISMOGRAPH. (Fig. II. last plate.)

	Maximum extent of motion.		Maximum frequency of vibrations.	
	Normal	Transverse	Normal	Transverse
At Station A 88 ft.	3^{mm}	$.9^{mm}$	4 per sec.	4 per sec.
At Station B 238 ft.	$.5^{mm}$	$.2^{mm}$	3 ,, ,,	3 ,, ,,
At Station C 388 ft.	$.2^{mm}$	$.1^{mm}$	3 ,, ,,	3 ,, ,,

At Station A. The normal disturbance commenced as a slight compression followed by an irregular tremor. The largest wave is the third having a range of 3^{mm} after which the motion rapidly dies down to $.4^{mm}$. At the commencement of the motion there are 4 vibrations per second but afterwards only 3.

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The transverse motion commences irregularly. At the end of the disturbance there are only 2 vibrations per second. Altogether there are 11 vibrations extending over 4 seconds.

At Station B. The normal motion practically consists of 4 large vibrations of nearly equal extent. They extend over about 1.5 seconds.

The transverse motion also consists of 4 nearly equal large vibrations executed in about $1.5^{sec.}$. The period is rather slower than that of the normal motion,

At Station C. In the normal motion two or three little ripples are to be observed at its commencement corresponding in time to two or three similar ripples in the transverse motion. These may possibly be due to a vertical component. They may also be traced in the diagram of the previous experiment.

About 7 vibrations appear in this diagram. They were executed in 2.5 seconds.

In the transverse motion the amplitude of motion is slightly less than in the normal. There are about 8 vibrations executed in about 2.5 seconds.

Vertical Motion. This was recorded at station B. It commences before the normal motion. At the commencement there are 6 small waves each having a range of $.15^{mm}$ performed at the rate of 8 per second. These are followed by a series of large vibrations with a range of $.4^{mm}$ performed at the rate of 2 waves per second.

Calculating as in the previous experiment, with a vertical motion of $.22^{mm}$ and a normal motion of $.38^{mm}$ we obtain 87 feet as a minimum depth for the origin of the disturbance. This we know to be incorrect. The vertical motion can not therefore be regarded as the result of a direct shock.

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3. EXPERIMENT

Five pounds of gunpowder exploded in bore hole Number III.

PENDULUM SEISMOGRAPH.

	Maximum extent of motion.		
At Station A 76 ft.	Normal motion about	.2^{mm}	Very irregular
At Station B 226 ft.	Motion about	.2^{mm}	

BRACKET SEISMOGRAPH. (Fig. III. last plate.)

	Maximum extent of motion.		Frequency of vibrations.	
	Normal	Transverse	Normal	Transverse
At Station A 76 ft.	.6^{mm}	.2^{mm}	5 per sec.	3.5 per sec.
At Station B 226 ft.	No motion			
At Station C 376 ft.	,,	,,		

At Station A. In a normal direction the first movement is a very slight extention. The fourth wave is the largest. At the end of the disturbance there are only 4 vibrations per second. Altogether there are 6 vibrations performed in 1.25 seconds. The transverse motion commences with one or two very small ripples. These are followed by 4 waves each having a range of about .2^{mm}.

At Stations B and C. No motion observed.

4. EXPERIMENT

2½ lbs of dynamite exploded in bore hole number IV.

PENDULUM SEISMOGRAPH.

	Normal	Transverse	Remarks
At Station A 64 ft.	3^{mm}	1.5^{mm}	
At Station B 214 ft.	1.2^{mm}		Also an oblique motion

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BRACKET SEISMOGRAPH. (Fig. IV. last plate.)

	Maximum extent of motion		Frequency of waves	
	Normal	Transverse	Normal	Transverse
At Station A 64 ft.	3.5^{mm}	1.2^{mm}	4 per sec.	3 per sec.
At Station B 214 ft.	.5^{mm}	.25	4 ,, ,,	
At Station C 264 ft.	.15	.1	3 ,, ,,	

At Station A. The normal motion commences with a decided compression of .4^{mm}. This is followed by three or four irregular back and forth motions of small amplitude. These are followed by the largest wave in the series. The whole of the motion was not recorded.

The transverse motion is characterized at its commencement by its irregularity.

At Station B. The normal motion commences irregularly. At the end of the disturbance there are only 2 waves per second. Altogether there are 11 vibrations performed in 4.5 seconds. The transverse motion commences irregularly with small waves. After this there are four well defined waves. Altogether 8 vibrations are described in 6 seconds.

At Station C. Both the normal and transverse motions are small and irregular. The transverse appears to have the quicker period.

Vertical Motion. This was observed at station B. It commences with a series of ripples each having a range of about .11^{mm}. Seven of these are described in a second. Next follow a set of larger waves with a maximum range of .7^{mm}. These recur in sets of three. These latter have a frequency of 3 per second. The periods of these waves it will be observed are quicker than those in the first experiment which were recorded 36 feet farther distant from the origin of the explosion.

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AMPLITUDE.

Hitherto the only measurements which have been given are those of maximum extent of motion or the length of a semi-vibration. The halves of these quantities may be taken as maximum mean amplitudes of wave motion. Another value for amplitude would be the quarter of the sum of two succeeding semi-oscillations.

An inspection of the diagrams, especially those of the normal motion as observed at the station nearest to the explosion, shew that instead of taking mean amplitudes, absolute amplitudes may be measured with regard to a line which would have been drawn by the pointer of the seismograph had no explosion occurred. Examining the diagrams in this way it is clear that a point has not oscillated with equal amplitudes on either side of its normal position. At the station nearest to the origin the amplitude of normal motion has almost invariably been much greater in the direction of the origin than in the opposite direction. The general result of an explosion has been to compress the ground by an outward impulse, after which it has recoiled inwards through a greater range than it moved outwards.

This peculiarity of motion is also observable at the second station in the fourth experiment. At the third station the motion has become so small and irregular that measurement of outward and inward motion from a neutral line are impossible. In the following table showing the outward and inward amplitudes of normal motion for the first three prominent waves at each station, those for the third station are therefore only approximate.

The first outward impulse at Station A which in the diagrams has the appearance of a quarter wave, subsequent investigations have shown to be a semi-oscillation. To represent a true amplitude its values .4 .5 and 1.3 as given in the following table require to be halved.

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AMPLITUDE OF NORMAL MOTION.

	Number of Wave.	Station A.		Station B.		Station C.	
		Outwards.	Inwards.	Outwards.	Inwards.	Outwards.	Inwards.
1. Experiment.	1	.4	.8	.25	.15	.05	.05
	2	.62	1.5	.35	.15	.05	.05
	3	.4	1.0	.25	.1	.05	.05
2. Experiment.	1	.5	1.5	.30	.2	.1	.1
	2	1.1	2.0	.4	.1	.1	.1
	3	.1	.7	.2	.2	.05	.05
4. Experiment.	1	1.3	1.7	.2	.4	.1	.1
	2	1.7	1.1	.12	.3	.1	.1
	3	.8	.2	.12	.3	.1	.1

When inspecting the above table it must be remembered that the distance of the three stations from the explosions was the smallest in the first experiment and greatest in the fourth experiment.

Another point of interest which may be obtained either from the table just given or from the values for the maximum extent of motion, is an approximate determination of the rate at which the motion dies out as a disturbance radiates.

From figures already given, the mean value in millimeters for the maximum semi-oscillation at stations A B and C in Experiments I II and IV are as follows.

Normal Motion.			Transverse Motion.		
A	B	C	A	B	C
2.8^{mm}	$.5^{mm}$	$.16^{mm}$	.85	.23	.1

or if we call the range of motion at A = 100, these numbers become.

100 18 6 and 100 27 12.

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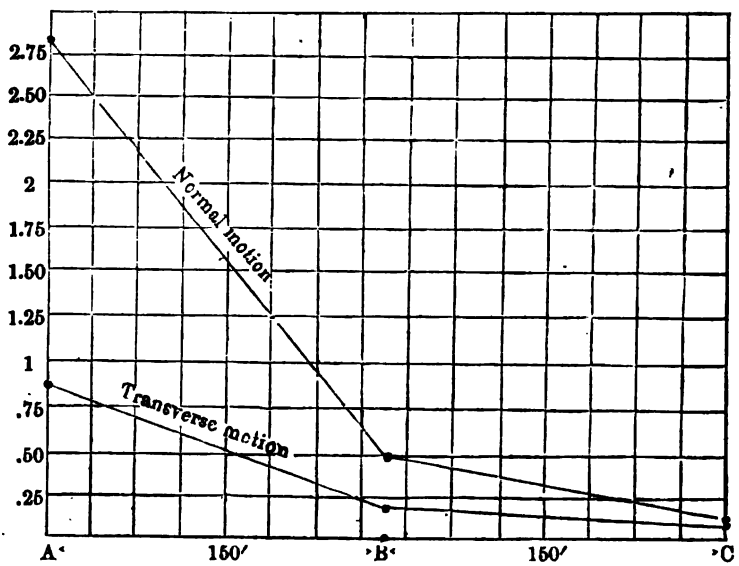
From this as from a direct inspection of the diagrams it is evident that the normal motion dies out very much more rapidly than the transverse motion.

Considering the transverse motion at each station as being equal to unity, then the ratio of the normal motion to the transverse motion is at each station as 3.3 : 2.1 : 1.6.

That is to say as the disturbance radiates the range of normal motion rapidly decreases until it is practically equal to the transverse motion.

These ratios together with the rate at which normal and transverse motion decrease are graphically shown in the accompanying diagram.

RANGE OF MOTION IN MILLIMETERS.



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In connection with the discussion of amplitude it is interesting to observe the manner in which motion dies out at any particular station. The most interesting examples are those of the normal motion at the first station. From the second or third wave which in these diagrams are invariably the largest, the decrease in amplitude for the three succeeding waves is exceedingly rapid. From this point however the decrease is relatively slow. The dying out in amplitude is more rapid on the inward side of motion than on the outward side.

PERIOD.

The following table shows the time taken in seconds to describe the principal waves indicated in the four diagrams (see last plate.)

The times indicated were obtained by direct measurement of the distance between crests of successive waves.

		Normal				Transverse			Vertical	
Experiment	Station	1st wave	2nd wave	3rd wave	near the end.	1st wave	2nd wave	near the end.	small waves.	large waves.
I	A	.24	.44	.8	.5	.4	.37	.5	.12	.5
	B	.46	.68	.4	..	..	.36	..	..	..
	C	..	.36	..	..	..	.43	..	..	..
II	A	.25	.5	.32	.5	.4	.4	.5	..	..
	B	.37	.61	.4	..	..	.38	.4	.14	.5
	C	..	.8	..	..	..	.34	..	..	..
III	A	.21	..	..	..	..	.32	..	..	..
IV	A	.25	.4	.27	..	.8	.35	..	..	..
	B	.33	.38	.33	.5	.33	..	.41	.12	.38
	C	..	.3	.3	..	.27	.3	..	..	..

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From an examination of the above table we see that—

1. As a disturbance dies out at any one station the period increases.
2. As a disturbance radiates the period increases.

These laws are the most clearly marked for the normal motion. It may here be pointed out that the measurements made on the diagrams obtained at station C on account of their smallness and irregularity, are not so accurate as those made on the diagrams obtained at stations A and B.

3. The vertical motion commences with a series of waves with an unusually short period. These are suddenly followed by a series with a long period.
4. Near to the origin of the disturbance, the transverse motion has at the commencement a period nearly double that of the normal motion.
5. At the end of a disturbance observed near the origin, or in diagrams taken at a distance from the origin, the period of normal and transverse motion approximate to each other.
6. The second wave obtained at station B in I and II with the unusually long period of over .6 second is in all probability a double wave due to the breaking up or elongation of the notched wave between the sinuses 1 and 2 which can be seen in Figs. I and II. last plate.

7. When we examine a diagram where there is a distinct movement of "shock" as for instance any of the diagrams of normal motion taken at the station (A) nearest to the origin, it is evident that the time taken to describe a half wave inwards is much less than to describe the preceeding or succeeding half wave outwards. To estimate these differences, measurements can be made of the time taken to describe quarter waves or amplitudes of wave motion. In making such measurements allowances have to be made for the arc which would be described by the pointer of the seismograph on the recording surface had the same been at rest.

Analyzing the normal motion obtained at station A in the different experiments we obtain the following results.

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		1st wave			2nd wave				3rd wave			
		1st quarter out	1st quarter in	2nd quarter in	2nd quarter out	3rd quarter out	3rd quarter in	4th quarter in	4th quarter out	5th quarter out	5th quarter in	5th quarter out
Experiments.	I	.18	.1	0	.2	.12	.08	.03	.2	.05	.05	.08
	II	.19	.02	0	.26	.2	.03	.03	.31	.02	..	..
	III	..	..	..	..	..	..	.02	..	..	..	..
	IV	0	.07	.07	.07	.2	.04	.07	..	..	..	..

It is evident that the sum of the times (which are given in fractions of a second) taken to describe the different quarters of any particular wave, ought to equal the time given as the period of the same wave in the previous table. However advantage has been taken of any little irregularity in the character of a wave to reduce the various measurements to their least possible value in consequence of which slight discrepencies between the two tables may here and there be detected. The object of obtaining minimum values will be seen when speaking of intensity. Comparing the inward movements or movements towards the origin with those described in the opposite direction, we see that the former are very much the quicker.

In the first wave the second quarter inwards is in two cases noted as having occured in an interval of time too small to admit of measurement. As measured on the diagram this movement has the anomalous appearance of having been described in less than no time. The only explanation which I am able to offer for this peculiarity is that the post on which the seismograph was fixed did not synchronise with the movements of the record receiver,—whilst the stand was moving forwards the receiver was moving backwards. Experiments on the relative motion of two neighbouring points will be spoken about later on. The quarter waves here referred to have been measured to the right and left of a line which would have been drawn by the pointer of the seismograph had there been

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no disturbance. It is evident that they might also have been measured as halves of each semi-oscillation.

MAXIMUM VELOCITY.

If we assume that the motion of the ground has been simple harmonic then the maximum velocity $V = \frac{2\pi a}{T}$ where,

a = the amplitude of motion and

T = the time taken to describe a complete wave.

In the adoption of this formula we are met with difficulties as to the manner in which a and T are to be measured. From the diagrams as already has been shown, either a mean amplitude or an absolute amplitude with regard to a certain line might be taken. A third value for amplitude would be quarter of a whole wave. Similarly T may be obtained by taking from the diagram the period of a complete wave, by doubling the time of a semi-oscillation, or by quadrupling the time of a quarter oscillation. Now as succeeding quarter or semi-oscillations have been described in different times, it is evident that three values for T may be obtained.

If therefore maximum velocities are calculated on the assumption that the motion has been simple harmonic it is possible to obtain nine different values for V.

A conclusion which the analysis of the diagrams here presents to us, is that the vibrations are in all probability not strictly simple harmonic motions, and whatever calculations respecting maximum velocities and other quantities are made on such assumptions, at the best can only be regarded as approximate.

The following table of maximum velocities in millimeters per second has been calculated for the normal motion at station A on the assumption that

a = the amplitude measured from the neutral line (see table p. 26.)

T = four times the time taken to describe a (see table p. 30.)

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		1st wave			2nd wave				3rd wave			
		1st quarter out	1st quarter in	2nd quarter in	2nd quarter out	3rd quarter out	3rd quarter in	4th quarter in	4th quarter out	5th quarter out	5th quarter in	6th quarter in
Experiments.	I	4.6	6	90*	6	7.5	11.2	75	1.1	12	12	50
	II	4.7	37.5	225*	8.6	8.2	55	100	10	7.5	7.5	52
	III	..	..	..	..	..	..	22.5	..	..	..	..
	IV	10	28	36	36	12	64	24	..	..	..	..

The velocities marked with an asterisk are probably too great owing to the assumption made with regard to the value of T. This assumption was that $\frac{T}{4} = \frac{1}{100}$ second.

At station B the maximum velocities calculated on similar assumptions are as follows.

		1st wave			2nd wave				3rd wave			
		1st quarter out	1st quarter in	2nd quarter in	2nd quarter out	3rd quarter out	3rd quarter in	4th quarter in	4th quarter out	5th quarter out	5th quarter in	6th quarter in
Experiments.	I	1.6	4	3.2	4.5	3.5	5.2	3.5	2.2	2.3	3.7	2.3
	II	2.5	1.2	4.5	3	6	6	5	2.3	2.3	3	5
	III	17	28	7.5	4	4	4	3	2.7	1.3	3	2

At station C the maximum velocities are approximately as follows.

I	Experiment	.7 to 3mm	per second
II	,,	1.5 to 10mm	,, ,,
III	,,	3m	,, ,,

In addition to these calculations of maximum velocities, calculations have been made of the same quantities by a method pointed out by Mr. T. Alexander in which there is no assumption made as to the nature of the motion (see Trans: of the Seis: Soc. Vol. VI. p. 13.)

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The data on which these calculations are based, are the path traced by the pointer of the seismograph by the unknown motion of the pointer, the known linear velocity of the plate, and the length of the pointer.

As the construction to obtain maximum velocities by this method is chiefly dependent on the accuracy with which tangents can be drawn to the slope of the waves at their neutral point, the greatest accuracy has been obtained from the waves which were described slowly. In the case of the normal motion at A, the inward motion was described so quickly, as has already been pointed out, that calculations of maximum velocity in this direction have been neglected.

The waves which have been calculated are as follows.

MAXIMUM VELOCITY OF NORMAL MOTION IN MILLIMETERS PER SEC.

No of Experiment	1st wave: 1st quarter out	2nd wave: 2nd or 3rd quarter out	3rd wave: 4th or 5th quarter out	4th wave: 6th or 7th quarter out	
1st	3.6	6.5	6.5	8.	at A.
2nd	3.4	8.5	7.6	5.4	
4th	9.5	11.	10.4	7	
1st	1.2	3.5	2.4	..	at B.
2nd	2.	4.	1.8	..	
4th	1.4	4.4	2.6	1.1	
1st	.8	.6	..	..	at C.
2nd	.7	1.4	1.	..	
4th	.8	1.2	1.5	..	

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In comparing these results with the results given in the three previous diagrams, it will be observed that if not absolutely identical, they are practically so when compared with mean values for each of the two corresponding quarters given separately in preceeding tables.

For the outward motion of the ground such comparisons, afford a means of estimating the amount of error which has entered into the numerous calculations which have been repeatedly made on earthquake diagrams, the assumption made in such calculations being that the motion was simple harmonic.

INTENSITY OF MOVEMENT.

In obtaining a value for the intensity of an earthquake many methods have been followed. Palmieri's seismograph indicates intensity by degrees. These degrees refer to the height up to which a certain quantity of mercury contained in tube, had been caused to oscillate. Inasmuch as this height is dependent on the depth of mercury in the tube, and the period and duration of the disturbance which causes its oscillation, it can only be regarded as a means of approximately estimating relative intensity.

Mallet in his reports to the British Association divides earthquakes into different classes according to the area over which they were felt, but at the same time remarks that "area alone affords no test of seismic energy". As a result of many observations I am led to believe that the area over which an earthquake is felt is dependent not only upon the initial force of the disturbance, but also upon its focal depth, the form and position of that focus, the duration of the disturbance, and the nature and arrangement of the materials which are shaken.

Seebach considered the initial intensity of earthquakes as proportional to the square of the radius of the disturbed area,—a method of calculation practically identical with that suggested by Mallet.

Rather than by adopting methods such as those here in-

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dicated it would seem that the intensity of an earth disturbance may be best estimated by the work it is capable of doing, as for example in overturning, projecting, or fracturing various bodies. A column may fall by the ground being suddenly moved beneath it. This gives it an impulse at its base, the reaction of its inertia acting at its center of gravity being equal to this. These two together produce rotation so that the column falls or tends to fall towards the side from which the impulse came according as the rotating moment is greater or less than its moment of stability.

The following note on this subject was given to me by my colleague Mr. C. D. West.

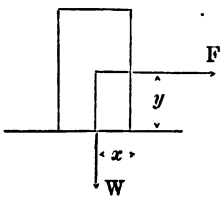

Fig. 17

Let the surface of the earth at any instant be undergoing an acceleration of velocity of f feet per sec. per sec. Let M be the mass of a column (see Fig.) resting on the ground, y the height of its center of gravity, and x its horizontal distance from the edge round which it may be supposed to turn.

Then the inertia of the column is equivalent to a force

$$F = Mf$$

acting horizontally through its center of gravity and tending to overturn the column, the overturning moment being

$$Fy = Mfy$$

This moment is opposed by the moment of the weight of the column Wx, and therefore when the column is on the point of overturning,

$$Wx = Fy = Mfy = \frac{W}{g} fy$$

$$\therefore \quad \frac{x}{y} = \frac{f}{g}$$

$$\therefore \quad f = g\frac{x}{y}$$

If f exceeds this value the column may go over, if less the column may stand.

If V is the maximum velocity of an earth particle as determined from an earthquake diagram, or by the projection

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of balls &c, and t being the time of acquiring this velocity, or $t = \frac{T}{4}$, where T is the complete periodic time, then f in the above formula may be considered as

$$f = \frac{V}{t} = \frac{V}{\left(\frac{T}{4}\right)}$$

If V and t are both very small this formula may be considered nearly correct, but if the amplitude is large then the upsetting value may be nearer to the maximum acceleration $\frac{V^2}{a}$ where a is half a semi-oscillation, and not the mean time acceleration (see Ninth set of experiments).

In the following table the maximum acceleration $\frac{V^2}{a}$ has been calculated for prominent normal motions. The ratio of this to the mean time acceleration is $\frac{\pi}{2}$.

TABLE OF MAXIMUM ACCELERATIONS.—IN MILLIMETERS PER SEC. PER SEC.

No. of Experiments.	At Station A			At Station B			At Station C		
	1st quarter out	2nd or 3rd quarter out	4 or 5 quarter out	1st quarter out	2nd or 3rd quarter out	4 or 5 quarter out	1st quarter out	2nd or 3rd quarter out	4 or 5 quarter out
1	32	60	47	5	49	22	12	7	
2	23	55	57	13	53	20	4	19	10
5	69	71	108?	9	64	33	6	14	22
Mean Values	41	62	70	9	55	25	7	13	10

Owing to the difficulties in making the necessary time observations it is impossible to make calculations of maximum acceleration for inward motions, which are evidently very much greater than the ones just given. From an inspection of the accompanying diagram Fig. 11. which represents mean

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values for the intensity of the three-waves given in the preceeding table, it would appear that for the area experimented on, the energy of motion varied inversely as some function of the distance from the origin.

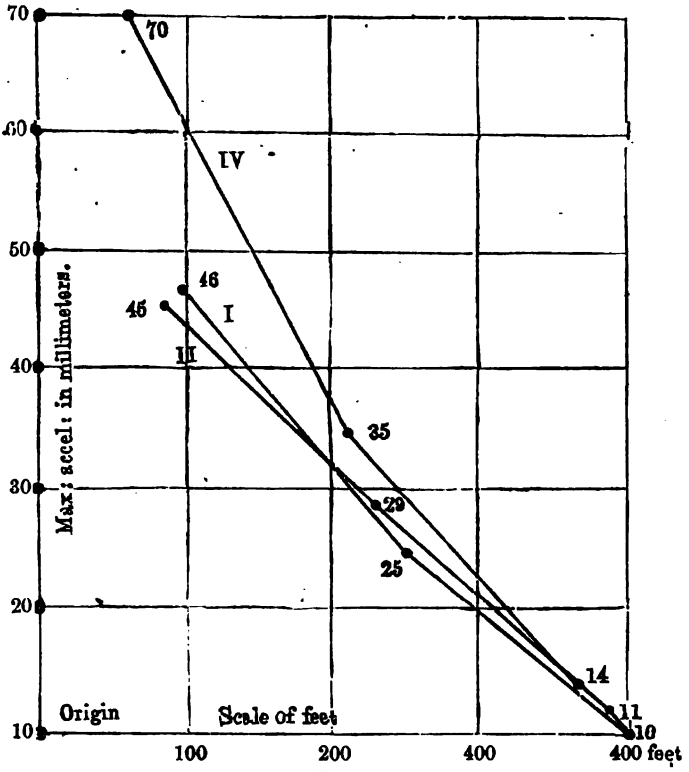

Fig. 11.

From the difference in the results obtained at the first station, which was at varying distances from the origin, it is probable that the rate at which energy was dissipated was greater between points near to the center of explosion than it was between points which were farther removed. Mr. T. Alexander has suggested that the total energy of the disturbance might be considered as proportional to the area enclosed between a curve of intensities and its axes, and having obtained such a curve for a unit disturbance produced for example by the

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explosion of a pound of dynamite we should have the means of giving absolute values for earthquakes providing their intensities had been measured at a sufficient number of stations.

RELATION BETWEEN NORMAL AND TRANSVERSE MOTION.

From an inspection of the diagrams it is evident that the normal motion has in all cases appeared on the recording surfaces a short interval ahead of the transverse motion. Unfortunately owing to irregularities in the diagrams we are unable to make accurate measurements of these intervals. One class of irregularities are probably due to displacements produced by sudden thrusts parallel to the length of the recording brackets, whilst another class may have been produced by sudden alterations in level accompanying the transit of surface waves. Evidences of such disturbances appear to exist in the diagrams.

For these reasons the results contained in the following table must only be regarded as approximate.

The time in seconds that the normal motion was recorded before the transverse motion is as follows.

	Distance from origin to			Time in seconds that the normal motion was recorded before the transverse motion.		
	A	B	C	A	B	C
	ft.	ft.	ft.	sec.	sec.	sec.
Experiment 1.	100	250	400	.23	.39	.51
,, 2.	88	238	380	.12	.33	.51
,, 3.	76	—	—	.1		
,, 4.	64	214	364	.03	.38	.5

On the assumption that these four records may be regarded separately, the accompanying curve has been drawn (Fig. 12). The actual points, for which it may be regarded as a mean value, are shewn by dots. From this diagram it would appear, that at a certain distance from the origin the normal motion outraces the transverse motion at a rapid rate, but as the disturbance radiates this rate decreases. It would seem that

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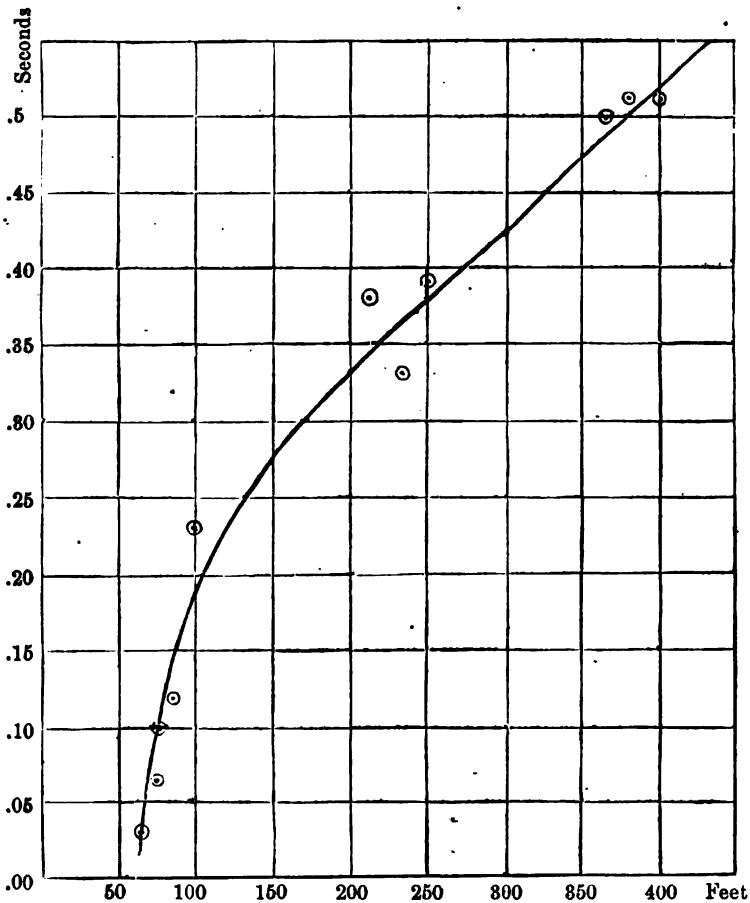

Fig. 12.

Time relation between Normal and Transverse Motion.

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the curve ought if produced to pass through the *real* origin of the disturbance. The origin referred to in the figure is the *epicentrum* of the shock.

For reasons already stated, as it is possible that there may be inaccuracies in these results, the above table and diagram yet require confirmation by farther experiments.

VELOCITY OF PROPAGATION.

In determining the velocity with which different vibrations were propagated, it is necessary to make measurements similar to those referred to in the last section, in consequence of which individual determinations are open to considerable error. The results most nearly correct are probably those determined as averages.

1. Horizontal motion.

	Normal Vibrations. Velocity in feet per sec.			Transverse Vibrations. Velocity in feet per sec.		
	A to B	B to C	A to C	A to B	B to C	A to C
1. Experiment	357	333	344	258	263	260
2. ,,	357	405	380	238	272	257
4. ,,	357	272	309	193	224	208
Average.	357	336	344	229	253	241

From the above table we see that the normal vibrations have been propagated at a greater rate than the transverse vibrations, the velocity ratio of the two between A and B being as 1.5:1. It will also be observed that for the normal motion the velocity is greater between stations near the origin, than between stations at a distance. This rule is apparently reversed for the transverse motion. It is quite possible that this result is due to errors in time measurement due to irregularities in the diagrams.

2. Vertical motion.

An inspection of the diagrams clearly indicates that vertical motion was always recorded at station B a considerable interval before there was any trace of either normal or transverse motions. In experiments 1, 3 and 4 the intervals

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between the appearance of vertical and normal movements were respectively .14 .25 and .29 seconds.

These numbers are calculated on the assumption that the first tremor observed in the normal record is due to the horizontal normal component. The intervals between the appearance of vertical motion and the first *decided* normal motion are respectively .53, .76 and .64 seconds. A mean value for these measurements is .22^{sec} which may be taken as the time by which the free surface wave outraced the normal component of horizontal motion in a distance of 234 feet. (the mean of 250, 238 and 214 feet).

Assuming that the normal motion had a velocity of 357 feet per second, the time taken to traverse 234 feet would be .65 seconds.

From this it follows that the vertical component travelled this distance in .43 seconds and therefore had a velocity of 544 feet per second.

Other results may be obtained by discussing the above data separately or by basing calculations on time measurements made between the first *decided* normal and vertical movements.

The most interesting point connected with this section of the subject is the observation that the preliminary tremors of a disturbance are due to a surface wave outracing the horizontal components of motion. Previous observers have determined the velocity of transit by observing the instant at which the surface of a vessel of mercury was set in vibration. By working in this way Mr. Gray and myself determined an average velocity of transit in hard mud (see first set of experiments) as 630 feet.

Mr. Mallet determined a velocity in sand as 824 .915 feet and in solid granite as 1664.576 feet per second.

General Abbott for like determinations in hard rocks obtained velocities of 3,000 and 8,300 feet per second. All high velocities like these usually accredited to the transit of earthquake motion, may possibly be due to the observers having recorded the surface wave.

Another phenomenon which the relatively high velocity of the surface wave may perhaps account for, are the prelimi-

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nary tremors which have so often been observed to accompany large earthquakes. As one example of such tremors I will refer to the earthquake of March 11th 1882 where I recorded such tremors extending over a period of 10 seconds before the arrival of any decided earthquake motion (see Trans. S.S. Vol. VII Pt. 2 p. 42) These preliminary tremors may also be connected with the sound phenomena which usually preceed earthquake motion by a short interval.

GENERAL OBSERVATIONS ON THE CHARACTER OF THE RECORDS.

In looking at the diagrams of the various explosions it will be observed that the majority of waves which have been recorded are characterized by their smoothness in outline.

A notable exception to this is to be observed in the first two or three waves of transverse motion recorded at station A. These are invariably irregular. The greatest irregularity occurs when the normal motion has been the greatest, as in the experiment No. IV, and least when the normal motion has been least as in experiment No. III.

This would appear to indicate that the source of the irrgularity must be traced to the earlier commencement of the normal motion which had disturbed the transverse bracket. Theoretically such a disturbance could not occur, but as has already been indicated p. 38., there are reasons for believing that such disturbances have an existence.

Another peculiar character to which attention may be drawn are the slight but sudden changes or notch like marks which are superimposed on several of the later waves in the normal record.

In experiments I, II and IV such notches may be observed on the left hand side of the first large wave. In experiment I, the notch occurs near the top of a wave, in experiment II about half way down the wave, whilst in experiment IV it occurs near the base of the wave.

By comparing the normal motion at A with that of the same explosion at B we see that by the time it has travelled

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to B the notches have been so far elongated that they practically constitute a second wave. In experiments I and II, a notched wave at A is included between the figures 1 and 2. The double wave at B resulting from this is included between corresponding figures. With this exception it may be said that it is practically impossible to recognize the same wave at two neighbouring stations. As a disturbance travels it appears to totally change in character. This observation appears also to hold good for actual earthquakes.

A third point to which attention may be drawn is, with the exception of the records taken at A, the indefinite manner in which the normal or transverse disturbance has commenced. This as already pointed out, may be explained on the assumption that the quickly transmitted vertical vibrations have affected the brackets recording horizontal motion before the actual arrival of the horizontal motion. To account for vertical motion affecting horizontal brackets we may suppose that the vertical waves caused slight tips in the soil.

The greatest irregularity in the character of the waves appears at station C where they are smallest. In experiments I and II attention may be directed to a series of small ripples appearing near the third time-interval.

The best idea of the actual motion which took place at any particular station, may be obtained by the inspection of a figure resulting from the combination of the normal and transverse motions. Three figures have been drawn for the first three waves at station A in experiments I II and IV (see Figs. 13, 14, 15.). To draw these figures the original diagrams were enlarged three times. The point from which motion commenced is shown by a black dot. The direction which the motion followed is shown by arrows on its path. From these diagrams it would appear that the first motion at station A, although characterized by many irregularities has a general direction in the line of the origin. The loops and irregularities in these figures are very similar to the irregularities, observed in the diagrams taken by seismographs with single indices writing on stationary plates (see Figs. 2. 3. 4. 5. 6.)

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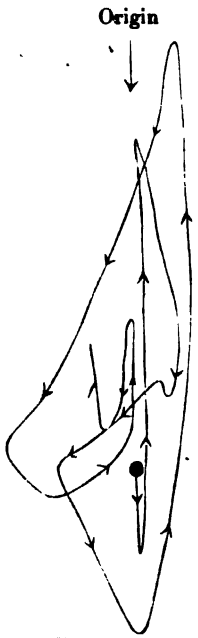
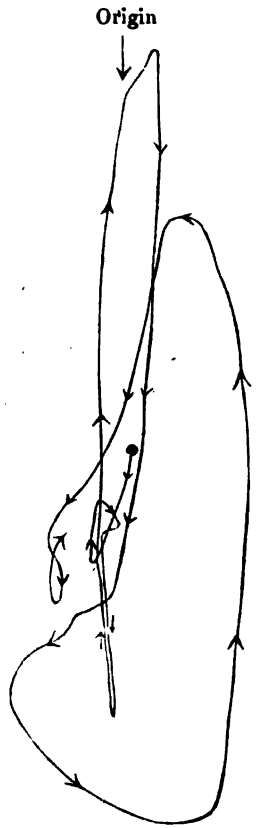
Experiment I.
(Fig. 18)



Experiment II.
(Fig. 14)



Experiment IV.
(Fig. 15)

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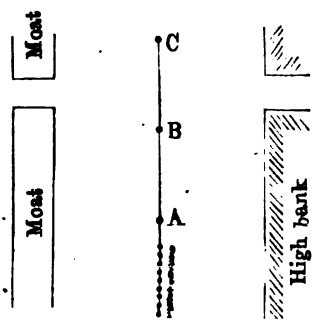
V. SERIES OF EXPERIMENTS.

These experiments were a continuation of the experiments previously made at Akabane and Tameike. Both at Akabane and Tameike the ground on which the experiments were conducted was soft and wet. The special object of the experiments described in the present paper was to determine the velocity with which vibrations of various descriptions were propagated in ground which was dry and hard. They were carried out on the 19th of March, in the grounds of the Chirikioku (Survey Department) in the central part of Tokio. The preparation for these experiments occupied several months,—much time being spent in making the required instruments, obtaining dynamite, telegraph wire, firing instruments, but above all in finding a locality for which permisson could be obtained to carry out the experiments.



The general arrangements for the experiments will be understood from the accompanying sketch. At A, B and C which are in a straight line, stakes were driven in the ground on the tops of which seismometers were fixed. The distance between A and B, and B and C was 200 ft. In a continuation of the line C B A commencing 30 ft distant from A, at the point 9, a bore hole 3 in. in diameter was sunk ten feet. Similar bore holes were sunk at 8, 7, 6, 5, 4, 3, 2 and 1, each 10 ft apart. From these bore holes which were dry, it was seen that the soil consisted of a few inches of vegetable mold, there 5 or 6 feet of a reddish earth containing pebbles and fragments of tile, and lastly at the very bottom of the hole a stiff blackish clay. The chief part of the bore hole was through the reddish gravelly soil.

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To the left of this line at a distance of from 200 to 300 ft. was a moat running along the base of the high ground upon which the Shôgun's castle was formerly situated. About 100 ft. away upon the right was a high bank which on the far side descended to the flat ground on which the greater portion of the city of Tokio is situated.

The first explosion was made in hole number 1, the second in number 2 and so on, each explosion in this way being 10 ft nearer to A than the one which proceeded it. The holes were tamped with loose earth. The dynamite which was employed was kindly given to me by Mr. Denys Larrieu a member of the Seismological Society.

The charges which were employed for the different experiments and the distances of A B and C from the explosion will be seen from the following table. Eighteen cartridges and six primers weighed 5 lbs.

					A ft	B ft	C ft	
I	8	Cartridges &	2	primers	110	310	510	
II	10	,,	6	,,	100	330	500	(missed fire)
III	10	,,	1	,,	90	290	490	
IV	7	,,	1	,,	80	280	480	(hole 5 ft deep)
V	5	,,	0	,,	70	270	470	
VI	10	,,	0	,,	60	260	460	
VII	12	,,	3	,,	50	250	450	
VIII	12	,,	3	,,	40	240	440	
IX	0	,,	13	,,	30	230	430	No result, the charge being too small

The first five of these explosions were employed to determine the speed of vertical vibrations. Numbers VI and VII for the speed of normal vibrations and VII and IX for the speed of transverse vibrations.

The instruments employed to record vertical vibrations were as follows.

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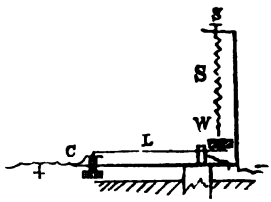

S is a brass wire spring 2.5 cm. in diameter stretched by a lead weight W (about 1 lb.) to nearly double its length, and making about 27 oscillations in 20 sec. By means of the supporting screws this was so arranged that a pointer on the under side of W justs rested on the short arm of the lever L, the longer arm of which was a straw. This lever almost balances on its fulcrum. From the fulcrum a very thin wire passes down the straw to its end where it makes contact with a small copper plate C fixed on the head of a screw. The whole of this arrangement is carried on the frame shown in thick lines, which in turn is carried on a stake driven in the ground.

It is very evident that any upward motion of the ground will tend to leave the weight W at rest. The fulcrum of the lever having been raised, the short end being in contact with W and therefore at rest, the longer end must be caused to move upwards a distance which will be some multiple of the actual upward motion of the ground. This multiplication of the upward motion of the ground will be as the short arm of the lever is to the total length of the lever. In the instruments employed the multiplication was 12.

By this arrangement it is evident that a very slight upward motion would be sufficient to break the contact between the copper plate and the wire at the long end of the lever.

An instrument like the one described covered by a small tent was placed at each of the stations A B and C.

Each of these instruments was placed in an electric circuit, the current passing from the fulcrum down the straw to the copper plate C.

In each of these circuits an electro-magnet was placed which so long as the circuit was closed deflected a lever at the end of which these was a needle point resting on a smoked glass plate. This smoked glass plate just before the explosion took place, was caused to move by being placed on a carriage

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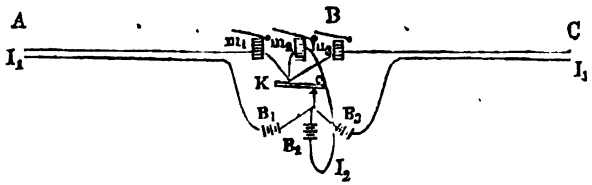
drawn by a falling weight. The motion of this carriage was regulated by a string wound upon an axle to which was attached a fan revolving in a vessel of oil. To measure the speed of the carriage, a small pendulum was so arranged that at each of its swings it made a tick upon the moving glass.

The electrical connections will be understood from the accompanying sketch.



I_1 I_2 and I_3 are the three instruments each of which has its own circuit, battery (B_1 B_2 and B_3) and magnet (M_1 M_2 M_3).

The batteries, magnets, moving carriage &c. were arranged on a table in a large tent close to B.

The order of proceeding was as follows.

The instruments I_1 I_2 and I_3 were all carefully adjusted by the same person. This adjustments was in all cases so delicate that it was impossible to walk on the ground in the neighbourhood of the instruments without breaking the contact as was seen by the movements of the lever connected with the magnet. All being adjusted, the key K was depressed and all the levers deflected, the pendulum was set swinging, the carriage with the glass plate set in motion, and shortly afterwards by depressing the lever of one of Breguets electrical exploders the explosion took place.

The result obtained was, that when the instrument at A was affected the circuit was broken and the straight line being drawn by the lever of M_1 was broken. Shortly after this when the disturbance reached B_2, the line being drawn by M_2 was broken and finally M_3 was broken.

For normal and transverse motions, bracket seismographs having a multiplication of about 12 were used.

These instruments were so arranged that a fine wire was carried down the writing index as one terminal of an electric

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circuit, this rested on the apex of an inverted V shaped piece of wire as the other terminal. A slight motion of this index to the right or to the left sufficed to break the circuits.

The remainder of the apparatus in connection with these bracket seismographs was similar to that employed with the instruments for vertical motion.

The results which were obtained are shown in the table on the next page. Numbers II and IX of these experiments are omitted, the first because the explosion missed fire and the second because the disturbance produced by the explosion was too small to produce an effect at the stations B and C.

The table of numbers proportional to the intensity of the shock at A were obtained by dividing the numbers proportional to the charge of dynamite by the distance from the bore hole to station A., it being assumed that the intensity of a disturbance is proportional to the quantity of the explosive which produces it, and inversely proportional to the distance from the scene of explosion. The reason for this latter assumption will be seen by reference to page 37.

When examining this table, attention may be drawn to the following facts.

1. It is extremely probable that the so called Normal vibrations are in reality vertical movements which caused the circuit to be broken by producing a tip in the soil and throwing the pointer of the bracket seismograph out of contact. The Transverse vibrations may really be transverse motions, inasmuch as the pointer of a bracket would not be thrown out of contact by waves advancing parallel to its length. For farther evidence for such suppositions see the fourth series of experiments.
2. For experiments VI VII and VIII two velocities are given for the same time intervals. The reason for this is that after the fifth experiment all the electrical connections had to be rearranged with the change of instruments. In doing this confusion appears to have arrisen between the wires leading to A and B, in consequence of which the recorded time intervals may refer to A C or to B C. The latter is more probably correct.

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		Velocity in feet per second.			Charge of Dynamite in lbs:	Distance from bore hole to A.	No. proportional to intensity at A.
		1st 200 ft. A—B	2nd 200 ft. B—C	1st 400 ft. A—C			
Vertical Vibrations	I	350	186	243	2.25	100	.022
	III	..	211	..	2.50	90	.027
	IV	352	284	281	2.	80	.025
	VI	348	282	277	1.25	70	.017
Normal or Vertical Vibs:	V	..	208 or 407		2.50	60	.041
	VII	..	288 or 476		3.25	50	.065
Transverse Vibrations	VIII	..	172 or 344		3.25	40	.081

The general results obtainable from the above table appear to be as follows.

1. The velocity of transit is greater for the first 200 feet than it is for the second 200 feet. In other words as a disturbance radiates its velocity decreases. For the first 200 feet the average velocity was 348 feet per second whilst for the second 200 feet it was 213 feet per second.
2. For the first 200 feet the velocity of transit varies directly as the intensity of the disturbance at A,—the greater this intensity the greater the velocity. For the second 200 feet this law is not so marked.
3. The average velocity over the whole range from A to C may be taken as a mean of experiments I IV and V. It equals 267 feet per second.
4. The lowest record is that for transverse motion.

These results can only be looked upon as confirming results obtained by General H. L. Abbot, of the United States Corps of Engineers (see American Journal of Science and Arts Vol. XV No. 87 p. 178).

Thus to show that rate varies with the intensity of the initial shock General Abbot quotes from his observations the following.

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400 lbs.	of	dynamite	gave	8814	ft.	per	second
200	„	„	„	„	8730	„	„	„
70	„	„	„	„	8415	„	„	„

And to show that the velocity of the wave decreases with its advance the followng is quoted.

200 lbs.	of	dynamite	give	for	1	mile	8730	ft.	per	second
„	„	„	„	„	„	5	„	8280	„	„	„
50,000	„	„	„	„	„	8	„	8300	„	„	„
„	„	„	„	„	„	13½	„	5300	„	„	„

It may be objected that some of these observations were made upon disturbances propagated through different media all the stations not being in the same line. Also the experiments were made at different times by different observers.

The late Mr. Mallet also raised many objections to the results obtained by General Abbot. From the results of my own experience I am inclined to agree with the results obtained by General Abbot inasmuch as the objections even if valid can by their correction only make slight differences in the general results. The low velocities which I have recorded are almost as much below those obtained by Mr. Mallet as General Abbot's are above. This appears to be due, partly to the media in which I made my experiments, partly to the feebleness of the initial shock and partly to the instruments which I employed not been sufficiently delicate to record the small surface waves which outrace the movement of shock. It will be observed that in the experiments which I have described personal error, in observation have been avoided.

Measurement of Maximum Vertical Motion.

In three experiments the maximum vertical motion was approximately measured by fixing at right angles to the straw pointer of the instruments for vertical motion a short piece of very thin wire. After the instruments had been adjusted a glass plate standing vertically was gently pushed into contact with this so that if the pointer were pushed upwards, it would remain at its highest position in consequence of the friction of the wire against the glass.

The result was that the upward motion at A as composed with B was about as 7 : 3

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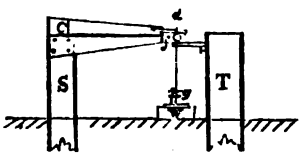
The actual upwards motion at A was in the III experiment about 3^{mm} in the IV experiment about 1.4^{mm}. At C the motion was too small to be measured.

Experiment to see how far two points near to each other synchronised in their motion.

In putting up seismometers especially those which give their records as two components it is usually assumed that we may support our apparatus on the heads of two posts driven in the ground at a short distance apart, the results obtained being the same as if we had supported our instrument upon one large post.

If however it could be shown that at the time of an earthquake the heads of two such posts did not synchronize in their motions, not only should we establish an important physical fact but also obtain information of practical value to the working seismologist.

With this object in view, in conjunction with the experiments which have been described, the following experiment was made. Near to the station A in a line parallel to A B C, two strong stakes S, T, were driven in the ground at a distance from each other of about 82^{cm}. From the head of S and projecting in the direction of T a light stiff board C was fixed. Down the middle of this there was a rib to give stiffness. The cross section of C was therefore thus +. On to the end of this there was screwed a piece of brass with a small hole in it at *d*. Immediately under this hole 1^{cm} below, there was a hole in a piece of brass attached to the stake T. Passing through these two holes was a piece of stiff wire with a small brass ball upon it. This ball which acted as a universal joint held the wire suspended in the lower piece of brass. The wire was continued downwards with a light bamboo index terminating at its lower end with a needle sliding through two small holes. This rested on a plate of smoked glass resting on a block of wood W.



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If S and T syncronized on their movements then it was assumed that *d* and *f* would always keep in the same vertical line. If however there was a want of synchronism then the difference in motion of these two points would be magnified about 20 times by the pointer *f g* which was 21^{cm} long.

The results which were obtained were as follows.

I Explosion. A mark was made on the glass about 15^{mm} long in a direction at right angles to the line A B C.

III Explosion. Several lines were made. At right angles to A B C about 10^{mm}, and inclined to this at about 45°, a line of 15^{mm}.

IV Explosion. Irregular markings about 3^{mm} long.

V Explosion. A line of about 4^{mm} long almost parallel to A B C, and also an irregular mark.

For remaining explosions the line of the two stakes S T was placed at right angles to the line A B C, and the movements were very much more definite. They were as follows.

VI Explosion. A line 10^{mm} long parallel to A B C.

VII Explosion. At least three large oscillations parallel to A B C, the largest being 29^{mm} long.

VIII Explosion. At least four large oscillations parallel to A B C, the largest being 38^{mm} long.

IX Explosion. Two or three small oscillations parallel to A B C at least 7^{mm} long.

The results obtained in these experiments would indicate that notwithstanding the lightness and stiffness of the arm C, it had not synchronized in its movements with the post to which it was attached in consequence of which the point *d* had not remained vertically above *f*. If such were the case, in the first two experiments *d* must have suffered a displacement relatively to *f* in consequence of the transverse component of motion whilst in the 6th, 7th, 8th and 9th experiments the displacement would be due to normal motion.

That the latter may be an explanation of the last four records is quite possible. To explain the existence of the first two records having been produced by a switch like movement in the arm C by a transverse motion is more hazardous. Certainly the result recorded in the third experiment can not

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be explained by such an assumption. Although these experiments when taken by themselves do not prove that there was a difference in phase in the movement of two neighbouring points, they are weighty evidence in favour of such movements having occurred when taken in conjuction with the peculiar characters observed in the diagrams of the fourth series of experiments, which characters could only be explained on the assumption that during a disturbance the stake on which a seismograph rested must have approached and receded from the plate on which the record was being written.

Experiments on the production of Earth Currents.

From near the scene of the explosions a telegraphic communication was established across a deep moat up to a hill, where the mechanical disturbances were practically not observable. Each end of this circuit was put to earth by means of two long crowbars, and in the circuit on the hill one of Clark's differential galvanometers was arranged. As either of the crow-bars was raised or depressed it was found that the current passing through the galvanometer varied, sometimes being positive and sometimes being negative. At a certain depth which was found by trial, the needle of the galvanometer remained at zero, and it was in this way that the adjustment to 'no current' was made previous to an explosion.

When an explosion took place, one earth bar being at distances of from 10 to 50 ft., a considerable current was always produced, and the needle of the galvanometer swung with violence until it reached a stop. The direction of swing was, in the few experiments which were made, always constant. Sometimes the needle remained permanently deflected, and at other times it gradually fell back towards zero.

These currents I regard as being due to a mechanical disturbance of one of the earth bars, causing a difference of contact with the soil; and, in consequence of this, an alteration in the moisture, oxidation surface, &c., at one end of the circuit, thus giving rise to a difference of potential relatively to the other end of the circuit.

No doubt actual earthquakes act upon the earth plates of telegraphic lines in a similar manner, but the currents which

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are in this way produced at the time of an earthquake are due to different causes than those which appear sometimes to have *preceded* earthquakes by considerable intervals of time.

Since making the above experiments Mr. T. Gray informs me as a result of a laboratory investigation, that there appears to be a difference in potential between two sides of a slab of rock when it is bent.

VI. SERIES OF EXPERIMENTS.

These experiments were made at the latter end of May 1882, on the same ground where the fifth set of experiments were carried out. The object of the experiments was to obtain the velocity of transit between five stations. Owing to the severity of the weather on the day for which permission had been obtained to carry on the explosions, many of the experiments unfortunately failed. Such results as were obtained are however of sufficient value to be recorded. The general arrangement of apparatus with the electrical connections was practically indentical with the arrangement employed in the last series of experiments. To record the passage of a disturbance at the different stations for the first two explosions "circuit closers" were used as breakers. This was done by pushing the mercury dish so that it came to contact with the index, on the side of the explosion. For a description of the "circuit closer" referred to, see Trans: Seis: Soc. Vol. IV p. 98. For the remaining experiments vertical spring instruments similar to those described on page 47 were employed.

The five stations A B C D and E were each 150 ft. apart and in the same straight line with the bore holes where Dynamite was exploded. The charges which were employed, together with the distance of station A from the different bore holes, and the general results which were obtained are given in the following table.

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No. of Explosion.	Velocity in feet per sec. A B	B C	C D	D E	Charge of Dynamite in lbs.	Distance from Bore hole to A.	No. proportional to intensity at A.
I	306	....	....	....	2	115 ft.	.017
II	260		264	....	2	105	.019
III	....	264	....	....	3.5 ?	75	.046 ?
IV	....	256	....	....	2.25	55	.040
V	....	....	....	288	2.5	45	.055
VI	397	....	....	357	2.25	35	.064
VII	...	285	....	....	2.25	35	.064

The deductions to be made from the above table are evidently similar to those made from the table of results given for the previous set of experiments. They are briefly,—

1. The velocity of transist is greater between points near to the origin of a disturbance than between points farther removed.
2. The velocity of transit varies directly with the intensity of the initial disturbance.

The actual velocities which have been recorded, it will be observed accord fairly well with those determined in previous experiments.

VII. SERIES OF EXPERIMENTS.

On May 28th 1882 I suddenly received notice that His Imperial Majesty the Mikado would on the 30th of the month visit the Meteorological Department (Chirikioku) where amongst other things he was desirous of witnessing the effects of dynamite in blowing up earth.

As the interval for preparation was so short I had not the time which was necessary to organize experiments which would require the use of seismographs or special instruments. The result was that the only advantage which could be taken of these explosions was to make observations requiring arrange-

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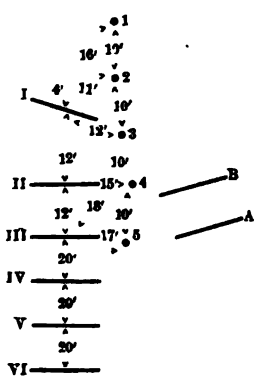
ments of a very simple kind. The ground selected for the experiments had in many places been very must cut up by trenches and other military works in consequence of which it was much drier and looser than that which had been previously employed.

The explosions were three in number, the charges being placed in 8 ft. bore holes each ten feet apart and in a straight line. In the first two explosions about 4 lbs. of dynamite was used. In the third, about 6.75 lbs. was employed.

Before a mine was exploded, three cylindrical blocks of deal each 6 inches in length and 6 inches in diameter were placed on the surface of the ground about 2 ft. 6 in. distance from the top of the hole and equally distant round it. A fourth block was placed above the hole. These blocks were marked A, B, C and D. At various distances from the bore hole heavy planks of wood were placed as stands for groups of wooden cylinders. Each group consisted of four cylinders the dimensions of which were as follows.

	Length	Diameter
No. of cylinder 1.	12in	4in
" " " 2.	10in	4in
" " " 3.	8in	4in
" " " 4.	6in	4in

The arrangement of the planks and groups of cylinders of which there were six will be understood from the accompanying figure.



In the diagram 5 bore holes are shown by black dots. Only the first three of these were employed. After the first explosion plank VI was moved to A, which was 42 ft from bore hole 2 and 15 ft from bore hole 5. After the second explosion, plank V was moved to B, which was 15 ft from 3 and 12 ft from 5. These measurements were made from the center of each plank.

The result of an explosion was to leave a conical hole about 15 ft in depth.

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The shallowness and probably the form of the hole is due to the falling debris which at the time of the explosion had been shot upwards in a fountain like column.

There is no doubt but that many of the columns were overturned by the falling materials.

The horizontal velocity of "shock" necessary to overturn a column is calculated from the following formula used by Mallet (see "The Admiralty Manual of Scientific Enquiry" p. 312)

$$V^2 = \tfrac{4}{3}\, g \sqrt{a^2 + b^2} \times \left(\frac{1 - \cos\theta}{\cos^2\theta}\right)$$

where a = height of the column

b = diameter of base of column

θ = the angle formed by the edge of base and a line drawn through the center of gravity.

For observations on the applicability of this formula see remarks at the end of the ninth set of experiments. The values given by this formula which are probably far below the true value, and the value for f or $\frac{V}{t}$ (see page 35.) also in feet are given in the following table.

If we assume a value for t say $\frac{1}{10}$ second, then values for V or the maximum velocity of the ground which corresponds to the velocity of projection are given in the last column of the table.

	Velocity of shock (Mallet.)	Acceleration to cause overturning. (Page 35)	Maximum velocity of ground.
Column 1	1.55 ft.	10.7 ft.	1.07
„ 2	1.75	12.8	1.28
„ 3	2.07	16.1	1.61
„ 4	2.49	21.3	2.13

I Explosion.

At plank I. Column 1. was just overturned and remained on the plank.

„ 2. was projected 2′. 3″.

„ 4. was slightly projected.

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Of these columns it may be assumed that column 1 was overturned by the shock indicating a maximum velocity of about 1.07 ft. Columns 2 and 4 were probably overturned or projected by the falling debris.

Owing to the haste with which the second hole had to be fired no time was allowed to measure the distance to which the blocks were projected.

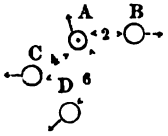
II Explosion.

At plank I. Column 1 was projected inwards 1 ft.
" 2 " " " 3 in.
" 3 " " outwards 10 in.
" 4 " " " 4 in.

Columns 3 and 4 may possibly have been overturned by their inertia and would indicate a maximum velocity of at least 1.28 ft.

Projection.

The position of the blocks and their direction of projection with regard to the bore hole which is shown as a black dot will be seen by reference to the accompanying diagram.



A was projected 46 ft. horizontally.
B " " 24 " "
C " " 27 " "
D " " 14 " "

The horizontal distances were measured from the bore hole. Assuming that the angles of projection for A B C and D were respectively 85, 70, 52 and 40 degrees then the initial velocity communicated to A B C and D must have been approximately 93, 33, 27 and 18 feet per second. The angles of projection were determined from the known depth of the charge, and the position of A B C and D with regard to the bore hole. From the form of the hole resulting from the explosion, and from the directions in which the blocks were thrown it is probable that the initial directions of projection were along a line joining the charge and the blocks. If the angles of projection which are taken as small as possible be increased, the resulting velocities for the given ranges will also be increased.

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III Explosion.

At plank I Column 1 was projected 7.5 in. outwards.
At plank II „ 2 „ „ 11 in. „
„ „ „ „ 3 „ „ 8.5 in. „
At plank V „ 1 „ overturned „

As all the columns which were projected or overturned were practically at the same distance from the explosion, we may take the maximum velocity as having been that necessary to overturn column 3, or 1.61 ft. per second.

Projection of Blocks.

A was projected 25 ft. horizontally
B „ „ 30 ft. „
C „ „ 34 ft. „
D „ „ 14 ft. „

The measurements were made from the bore hole. Taking the angles of projection as before, the initial velocities of A B C and D would be approximately 69, 38, 31 and 16 feet per second.

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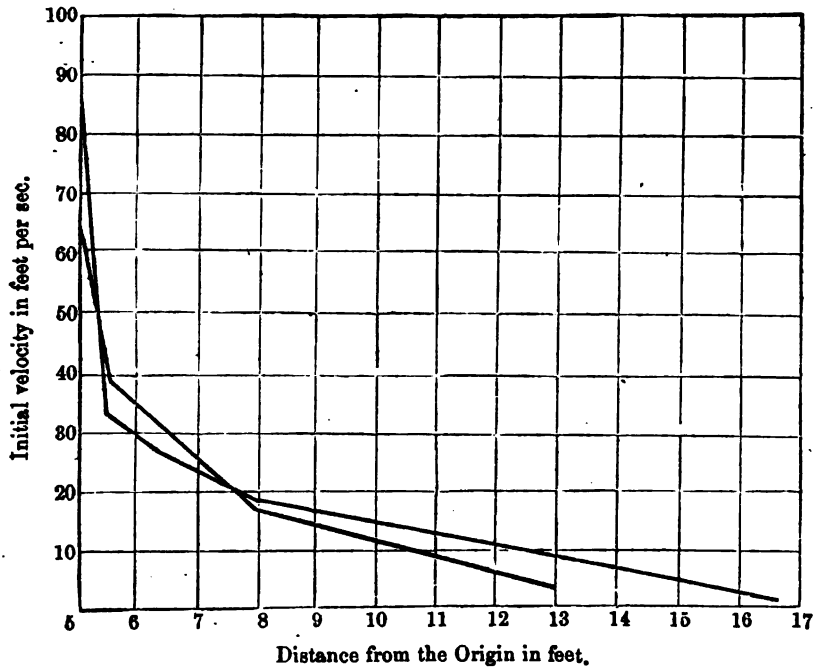
The few results which were obtained from these experiments are shown graphically in the accompanying figure. The horizontal distances are measured from the true origin of the explosion and not from the epicentrum.



As these experiments are few in number, and as they were performed under circumstances which precluded exactness in observation the value of the results which might be obtained from them by a close analysis is very doubtful. A general inspection of the above diagram however shews the enormous difference in the intensity of shock between points which are near the origin and points like those where observations were made in previous experiments which were relatively at a distance from the scene of explosion. Another fact to be observed is the exceedingly rapid decrease in the intensity of the disturbance between the epicentrum and points only one

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or two feet distant from it, these points like the epicentrum being within the area of excavation.

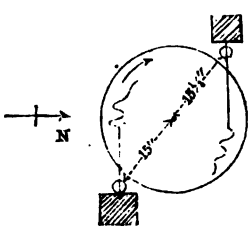
VIII. SERIES OF EXPERIMENT.

These experiments were made on July 6th 1883 in the grounds of the Chirikioku, near to the place where the seventh series of experiments were carried out.

The principal object of these experiments was to test different methods of determining the intensity of an earth disturbance. The disturbance was produced by the explosion of a charge of dynamite in a bore hole.

The general nature of the observations which were made was as follows.

1st. The record of the normal motion of the ground. This was obtained by a bracket seismograph on a revolving plate. To avoid the chance of error two brackets each placed to record normal motion were employed. These were so arranged that they wrote these records on two concentric circles as indicated in the accompanying plan.



During the experiments the pointer of the East Bracket was slightly broken so that its record was somewhat irregular.

At the time of the explosion a pendulum making 22 marks in 10 seconds was caused to tick upon the edge of the plate.

The total length of the pointers from the back pivot to the describing points = 8 $\frac{5}{8}$^{in}. Multiplication of the pointers = 13.

2nd. Recording the distance to which small lead and wood balls were projected from the top of a post.

The balls were one inch in diameter. The post were 4^{in}. square and 6 ft long. They were driven three feet into the ground. At the top they were notched and the balls were

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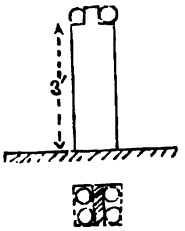

rested in the notches as shewn in the accompanying sketch.

A lead ball and a wood ball was in each noteh.

It was assumed that the projection was due to a horizontal shock. The formulæ employed to calculate the intial velocity of projection on this assumption was $V^2 = \frac{a^2 g}{2b}$

where a = the horizontal distance of projection
and b = the vertical height or 3 feet.

If we introduce into the calculations a value for ε or the angle of projection, based on the assumption that the post was struck by a shock coming direct from the origin, the resulting values for V would be increased.

3rd. Observations on the overturning of wooden columns. The dimensions of these columns together with the calculated accelerations and velocities of "shock" necessary to overturn them are given in the following table. For methods of calculating these quantities see seventh set of experiments.

No. of Column.	Length in inches.	Diameter in inches	Acceleration to cause overturning. (Page 85.)	Velocity of shock to cause overturning. (Mallet.)
			ft mm	ft mm
1	24	1	1.34 or 407	.121 or 36.3
2	18	1	1.79 or 544	.300 or 90
3	12	1	2.68 or 814	.409 or 120
4	10	1	3.22 or 978	.442 or 132
5	8	1	4.01 or 1219	.479 or 143
6	6	1	5.36 or 1629	.520 or 156

Groups of these columns were arranged in lines on narrow planks, bedded in the soil.

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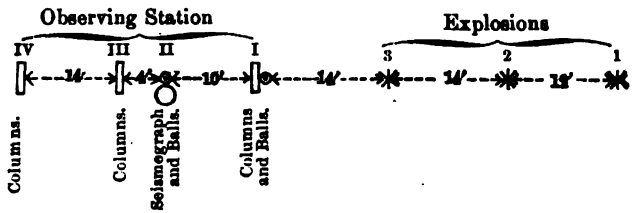
The ground was very dry and contained large stones.

The relative position of the explosions and the instruments will be understood from the accompanying plan

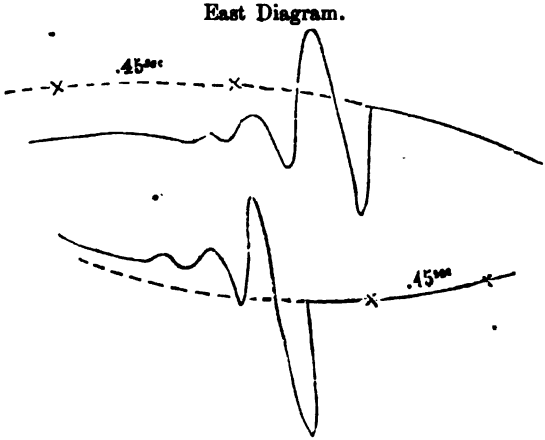


The explosions took place in holes about 8 ft deep so that from the surface to the center of the charge would be about 6 ft. In both the first and second explosion 5 lbs of dynamite was used, whilst in the third explosion only 3 lbs was employed.

The result of an explosion was to make a flat conical or saucer shaped hole about 8 or 9 feet in diameter and about 3 feet deep.

An example of the diagrams is shewn below. It represents the East and West records for the third explosion. To place them side by side one of them has been reversed.

East Diagram.



West Diagram.

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RESULTS OBTAINED.

1. *Explosion.* (5 lbs dynamite in a 6 ft. bore hole).

Station I. (40 ft. from the origin)

A lead and a wooden ball were each projected 6 inches in the direction of the origin. This would indicate a maximum velocity of 350 millimeters per sec. No columns fell.

Station II. (50 ft. from the origin)

A wooden ball was projected 14 inches away from the origin. This would indicate a maximum velocity in an outward direction of 795 millimeters per sec.

Records from seismographs.

The record given by the seismograph on the east side was not good, its pointer having been accidentally damaged. The records obtained from it have therefore not been analyzed. The record given by the seismograph on the west side furnished the following results.

	t	*a*	V
1st quarter out	.053	8	20
1st quarter in	.0053	8	184
2nd quarter in	.053	10	23
2nd quarter out	.026	5	23
3rd quarter out	.026	5	23
3rd quarter in	.039	6	17
4th quarter in	.039	6	17

"*out*" and "*in*" respectively refer to motion outwards and motion inwards towards the origin.

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t is the time in seconds to describe a quarter wave. For the 1st quarter *out*, t is the time and a is the range of a *semi* oscillation. The smaller the value for t the greater has been the difficulty in making measurements. a is 13 times the true amplitude. V is the maximum velocity in millimeters per second. This was calculated as before, the assumption being that the motion was simple harmonic.

Stations III and IV (54 and 68 ft from the origin)

No columns fell.

2. *Explosion.* (5 lbs of Dynamite in a 6 ft bore hole)

Station 1. (28 ft. from the origin).

A lead ball was thrown 2 ft towards the origin, indicating an intial velocity of 1397^{mm}. This ball evidently rolled after touching the ground and the calculated velocity is therefore too high. A wooden ball was thrown 7^{in} towards the origin indicating a maximum velocity of 396^{mm}.

The lead and wooden ball on the other side fell at the base of the stake. All columns were upset by debris.

Station 2. (38 ft from the origin).

A lead ball fell 5^{in} and a wooden ball 9^{in} to the south or away from the origin, indicating initial velocities of 291^{mm} and 519^{mm}.

Records from Seismographs.

Here again the record obtained from the seismograph on the east side was not good. The results obtained from the seismograph on the west side are given in the following table. The letters have the same meaning as before.

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			t	a	V
1st	quarter	out	.085	18	58
1st	,,	in	.008	18	235
2nd	,,	in	.096	20	24
2nd	,,	out	.017	20	185
3rd	,,	out	.063	9	16
3rd	,,	in	.087	9	12
4th	,,	in	.052	4	9
4th	,,	out	.043	4	10
5th	,,	out	.013	8	26
5th	,,	in	.013	8	26
6th	,,	in	.085	8	10

Stations 3 and 4. (42 ft. and 56 ft. from the origin) No columns fell.

3. *Explosion.* (3½ lbs of dynamite in a 6 ft. bore hole)

Station 1. (14 ft. from the origin)

A lead ball fell 9in and a wooden ball fell 11in towards the origin, indicating maximum velocities of 519mm and 645mm. A lead ball fell 18in and a wooden ball fell 15in away from the origin, indicating initial velocities of 1038mm and 850mm. Columns 1, 2 and 6 were overturned. Number 6 may have been knocked over by debris. The velocities indicated are respectively 36mm and 156mm (Mallet).

The overturning accelerations are 407, 544 and 1629mm per second per second.

Station 3. (24 ft. from the origin)

A lead ball was projected 4in towards the origin, indicating an initial velocity of 234mm. The wooden ball from this side was found on the opposite side of the post.

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A lead ball was projected 2^{in} and a wooden ball 5^{in} away from the origin, indicating velocities of 117^{mm} and 291^{mm}. Columns 1 and 2 fell away from the origin indicating velocities of shock of 36^{mm} and 90^{mm}. The overturning accelerations are 407^{mm} and 544^{mm} per second per second.

Records from Seismographs.

The notation is as before

	t	a	V
1st quarter out	.007	18	300
1st ,, in	.12	18	17
2nd ,, in	.12	15	14
2nd ,, out	.015	7	54
3rd ,, out	.015	7	54
3rd ,, in	.09	4	5
4th ,, in	.09	4	5

The maximum velocity calculated from the seismograph on the east side gave results rather greater than the above.

Station 3. (28 ft. from the origin)

Here columns 1 and 2 fell, indicating velocities the same as those determined by the overturning of columns at station 2. It is possible that these columns at station 3 may have been knocked over by debris.

Station 4. (42 ft. from the origin)

No columns fell.

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CONCLUSION.

Although all ordinary precautions were taken when making these experiments, it is clearly evident that they have yielded the most discordant results. The only case in which the maximum velocity deduced from a diagram has agreed with the initial velocity of projection has been in the third experiment, the former being 300^{mm} and the latter 291^{mm} per second. In all other cases the maximum velocity obtained from a diagram has been very much lower than that obtained by projection. One source of error in working on the diagrams has been the impossibility of accurately making the necessary measurements for time. When these are small neither they nor the quantities dependent on them like maximum velocities can be relied upon. In future experiments this might be obviated by having a record receiving surface moving at a higher velocity. The high velocity of initial projection probably arises from a want of rigidity in the post from which the balls were thrown, in consequence of which at the time of projection the post had a switch like motion. Assuming this conclusion to be correct, it indicates to us the caution which has to be observed in making calculations respecting earthquake motion as deduced from the positions in which bodies are found after having been projected. It also shews that the upright post of simple seismometers intended to indicate by projection must have great rigidity.

The "maximum velocity" given by Mallet for overturning is as might be anticipated not identical with the "maximum velocity" of projection. It is evidently a quantity dependent on the suddenness with which the column receives momentum. These quantities are farther discussed in the next series of experiments.

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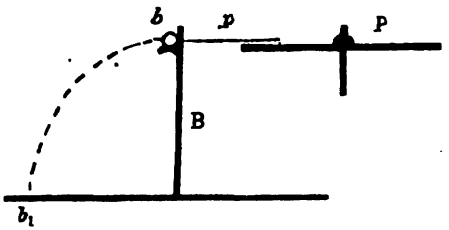
IX. SERIES OF EXPERIMENTS.

These experiments which were carried out in the workshop of the Imperial College of Engineering were made with the object of testing the accuracy of the methods which had been followed in analysing the records obtained in previous experiments.

They were as follows.

I. Experiments on Projection.



A flexible board B was clamped in an upright position. On the side of the board near to its end a small shelf was fixed on which a small wooden ball b could be rested. On the opposite side from the ball a light pointer p was hinged so that its outer end rested on the surface of a circular glass disc. The disc which was covered with smoke could be rotated at a known rate. An experiment consisted of the following operations.

First the board B was deflected and held in a deflected position by a small strut. The plate P was then rotated until it had acquired a uniform velocity after which the strut was suddenly removed. The result of this was to throw the ball from its shelf to some point b_1, whilst the pointer p described a series of waves on the revolving plate corresponding to the vibrations of the board.

From the horizontal distances, to which the ball was projected together with the vertical height through which it had fallen its initial velocity of projection might be calculated. This it was assumed would be equal to the maximum velocity of the board during its first swing, which quantity could either be taken directly by measurements made on the diagram drawn on the plate, or calculated from the diagram on the assumption of simple harmonic motion.

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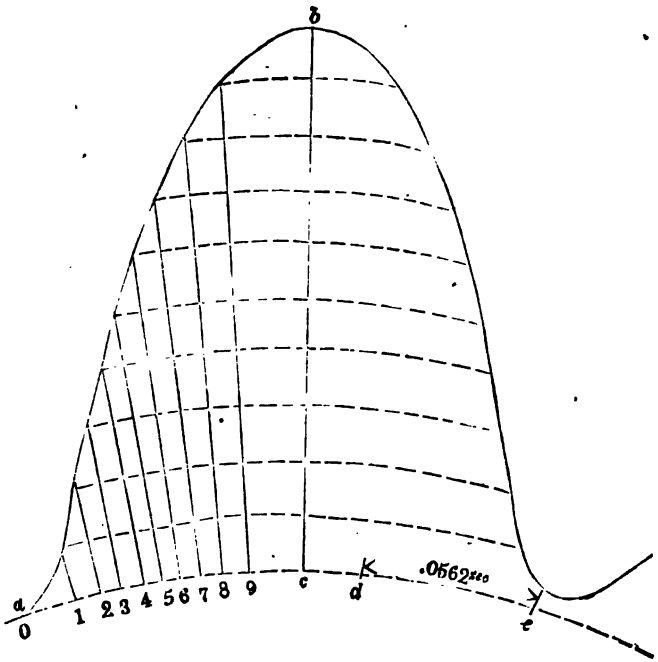

The above figure is a reproduction of the commencement of the diagram drawn in the second experiment. *a b* is the path of the pointer during the first swing of the board. *a c* represents the time taken to describe *a b*. *d e* is a unit of time given for the purpose of calculating a value for *a c*, or any fraction of it like 4, 5 or 5, 6. *a c d e* is a portion of the path described by the pointer before the strut was removed and the board was relieved from its deflected position.

1. *Experiment.*

In this experiment a board was used the vibrations of which had a period of .16^{sec}. It was deflected 72^{mm}. The ball was projected 2^{ft}.8^{in} from a height of 4^{ft}.6½^{in}.

The maximum velocities obtained were,

1.	On the assumption of S.H.M.	1305^{mm} per sec.
2.	By direct measurement	1511^{mm} „ „
3.	By projection	1524^{mm} „ „

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2. *Experiment.*

In this experiment a board was used the vibrations of which had a period of $.20^{sec}$. It was deflected 72^{mm}. The ball was projected $2^{ft}.3^{in}$ from a height of $4^{ft}.6\frac{1}{2}^{in}$.

The maximum velocities obtained were.

1.	On the assumption of S.H.M.	1056^{mm} per sec.
2.	By direct measurement.	1142^{mm} „ „
3.	By projection.	1285^{mm} „ „

In making the calculation on the assumption of simple harmonic motion in the formula $V = \frac{2\pi r}{T}$ the value for r was taken as $\frac{cb}{2}$ (see Fig. p. 71) whilst T was taken as twice the value calculated for $a\,c$.

Although the conditions under which the dynamite diagrams were obtained differ from those of the spring board, it would appear that the methods of calculation followed when analysing the latter are probably the more correct and therefore to be followed in analysing the former. For this reason the first motion of shock in the dynamite diagrams has been considered as a semioscillation and not as a quarter oscillation.

Another point which these experiments clearly indicate is that the initial velocity of earthquake motion as estimated by the range through which bodies have been projected, closely corresponds to the maximum velocity calculated or directly measured from a diagram.

The slight discrepency between these two quantities in these experiments partly arises from the fact that the ball was not projected horizontally from the top of the bent spring but was projected slightly upwards.

The difference between the calculated velocity and the velocity directly measured from the diagram may be due to the fact that the motion was not strictly simple harmonic.

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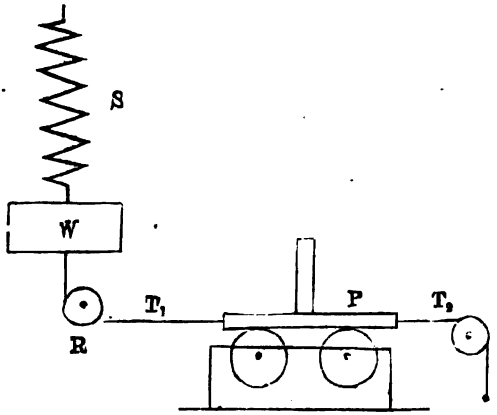
II. Experiments on Overturning.

These experiments were made as follows



S is a strong spring stretched by a 12 lb weight W.

A light strip of wood P resting on two large friction rollers is attached to W by means of a silk thread T_1 passing round a light pulley R. A second thread T_2 and a small weight balances the board P on the pulleys. When W is depressed and suddenly set free it oscillates for a considerable time, the board P moving with it back and forth about the same distance to the right and left of its neutral position. The columns overturned were placed on P as shewn in the figure. As the whole of the apparatus excepting the weight and spring was very light and the friction small, the free motion of the weight W, which made 14 complete vibrations in 10 seconds, was but little changed. The columns to be overturned butted against the edge of a strip of note paper pasted on the board P.

The object of this was to give sufficient friction to prevent the board suddenly moving beneath the columns without exerting any overturning effort.

An experiment consisted in finding out the distance to which W had to be depressed and then suddenly freed, to overturn a given column. Knowing the period of the spring and its amplitude, the maximum velocity V, the mean time acceleration $\frac{V}{t}$ and the maximum acceleration $\frac{V^2}{a}$ might be calculated. An acceleration f sufficient for verturning may also be calculated from the dimensions of

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the columns (see page 35). The relationship between these three quantities will be seen by inspection of the following table.

Dimensions of wood column		Overturning acceleration. (p. 35).	Deflection to cause overturning = a.	Acceleration $\frac{V}{t}$ due to deflection.	Maximum acceleration $\frac{V^2}{a}$
Length	Diam.				
2^{in}	1^{in}	16.1^{ft}	2.75^{in}	11.29^{ft}	17.78
3	1	10.7	2.25	9.28	14.49
4	1	8.05	1.50	6.15	9.65
6	1	5.36	1.875	5.64	8.85
8	1	4.01	1.125	4.61	7.24

Examining the above table it will be observed that the calculated acceleration sufficient to overturn the body is equal to the mean acceleration as calculated from the formula $\frac{V}{t}$ when the deflection is small. For larger deflections it lies between this value and the value calculated by the formula $\frac{V^2}{a}$.

These experiments show that the overturning power of an earthquake as determined from the dimensions of a body which has been overturned, are at the best only approximative. The maximum acceleration of an earth particle lies above the value of f as calculated from the dimensions of a column which has been overturned and the mean time acceleration lies somewhat below it.

Mallets formula for the overturning of a column assumes either that the column is moving with a velocity V and is suddenly checked at the base, or else that the earth is moving with velocity V and the column is placed suddenly on it. As these conditions do not appear to exist in an earthquake the formula is inapplicable.

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X. SERIES OF EXPERIMENTS.

These experiments were made in 1881 in the Physical Laboratory of the Imperial College of Engineering by me in conjunction with Mr. Thomas Gray who was then acting as Professor of Natural Philosophy.

The object of the experiments was to obtain data to calculate the theoretical velocity of earthquake waves through certain rocks. To obtain these data columns of rock 60 centimeters in length and 4 centimeters in diameter were subjected to cross bending and torsion from the results of which experiments Young's modulus and the modulus of rigidity were calculated.

Subsequently the modulus of rupture was determined and also the length modulus of crushing.

The following table gives the results of the experiments.

	Velocity of normal vibrations in feet per sec.	Velocity of transverse vibrations in feet per sec.	Ratio of normal to transverse.
Granite	12957	7185	1.80
Marble	12500	6824	1.83
Tuff	9350	6857	1.36
Clay rock	11417	8333	1.37
Slate	14796	9333	1.58

From an inspection of the above table it would appear that the ratio of the speed of normal and transverse motions is not constant. The softer and less elastic the rock is, the nearer do the two velocities approach each other.

It must be remembered that the rocks experimented on were nearly homogeneous whilst earthquakes are transmitted through rocks which may be extremely heterogeneous and fissured. Mallet who made experiments "on the compressibility of solid cubes of these rocks obtained the mean modulus

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of elasticity" with the result that "nearly seven eights of the full velocity of transit due to the material if solid and continuous, is lost by reason of the heterogeneity and discontinuity of the rocky masses as they are found piled together in nature".

A fuller account of these experiments will be found in the Philosophical Magazine. 1881.

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GENERAL RESULTS.

In reading these conclusions it must be remembered that they only refer to experiments performed in certain kinds of ground.

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1. Effect of Ground on Vibration.

1. Hills have but little effect in stopping vibrations (p. 8.)
2. Excavations exert considerable influence in stopping vibrations (p. 8.)
3. In soft damp ground it is easy to produce vibrations of large amplitude and considerable duration. (First, third or fourth set of experiments)
4. In loose dry ground an explosion of dynamite yields a disturbance of large amplitude but of short duration. (Diagrams of eighth set of experiments)
5. In soft rock it is difficult to produce a disturbance the amplitude of which is sufficiently great to be recorded on an ordinary seismograph. (Second set of experiments).

2. General Character of Motion.

1. The pointer of a seismograph with a single index first moves in a normal direction after which it is suddenly deflected and the resulting diagram yields a figure partially dependent on the relative phases of the normal and transverse motion which phases are in turn dependent upon the distance of the seismograph from the origin. (First set of experiments. p. 8. Figs. 2, 3, 4. also illustrated in records of other experiments.)
2. A bracket seismograph indicating normal motion at a given station commences its indications before a similar seismograph arranged to write transverse motion. (Diagrams of fourth set of experiments.)
3. If the diagrams yielded by two such seismographs be compounded they yield figures containing loops and other irregularities not unlike the figures yielded by the seismograph with the single index (see p. 44.)

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4. Near to an origin, the first movement will be in a straight line outwards from the origin, subsequently the motion may be elliptical, like a figure 8, and irregular. The general direction of motion is however normal.
5. Two points of ground only a few feet apart may not synchronize in their motions (pp. 52. 30.)
6. Earthquake motion is probably not a simple harmonic motion (p. 31.)

3. Normal Motion.

1. Near to an origin the first motion is *outwards*. At a distance from an origin the first motion may be *inwards*. (Second and fourth experiments)
   As to whether it will be inwards or outwards is probably partly dependent on the intensity of the initial disturbance and on the distance of the observing station from the origin.
2. At stations near the origin the motion *inwards* is greater than the motion outwards. At a distance the inward and outwards motion are practically equal (pp. 25. 26. 27.)
3. At a station near the origin the second or third wave is usually the largest after which the motion dies down very rapidly in its amplitude, the motion inwards decreasing more rapidly than the motion outwards (p. 26.)
4. Roughly speaking the amplitude of normal motion is inversely as the distance from the origin (see pp. 26. 27.)
5. At a station near an origin the period of the waves is at first short. It becomes longer as the disturbance dies out. (see diagrams generally, also p. 29.)
6. The semi-oscillations *inwards* are described more rapidly than those *outwards*. (see diagrams generally, also p. 29.)
7. As a disturbance radiates the period increases. (see diagrams generally, also p. 29.) Finally it becomes equal to the period of the transverse motion. From this it may be inferred that the greater the initial disturbance the greater the frequency of waves (see table p. 28.)

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8. Certain of the inward motions of "shock" have the appearance of having been described in less than no time. (for explanation see p. 30).
9. For tables shewing the maximum velocity of normal motion (p. 33.)
10. For diagram shewing the intensity of normal motion (p. 37.)
11. The first outwards motion which on diagrams has the appearance of a quarter wave must be regarded as a semi-oscillation. (p. 72.)
12. The waves on the diagrams taken at different stations do not correspond. (see diagrams for fourth experiments.)
13. At a station near the origin a notch in the crest of a wave of shock, gradually increases as the disturbance spreads, so that at a second station the wave with a notch has split up into two waves. (p. 42. 43.)
14. Near the origin the normal motion has a definite commencement. At a distance the motion commences irregularly the maximum motion being reached gradually. (for possible explanation of this see p. 43.)

4. Transverse Motion.

1. Near to an origin the transverse motion commences definitely but irregularly. (see diagrams.)
2. Like the normal motion the first two or three movements are decided and their amplitude slightly exceeds that of those which follow. (see diagrams.)
3. The amplitude of transverse motion as the disturbance radiates decreases at a slower rate than that of the normal motion. (p. 27.)
4. As a disturbance dies out at any particular station the period decreases. (p. 29.)
5. As a disturbance radiates the period increases. (p. 29.) This is equivalent to an increase in period as the intensity of the initial disturbance increases.
6. As we recede from an origin the commencement of the transverse motion becomes more indefinite. (see diagrams)
7. It will be observed that the laws governing the trans-

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verse motion are practically identical with those which govern the normal motion the only difference being that in the case of normal motion they are more clearly pronounced.

5. Relation of Normal to Transverse Motion.

1. Near to an origin the amplitude of normal motion is much greater than that of the transverse motion. (pp. 26. 27.)
2. As the disturbance radiates the amplitude of the transverse motion decreases at a slower rate than that of the normal motion, so that at a certain distance they may be equal to each other. (see p. 27.)
3. Near to an origin the period of the transverse motion may be double that of the normal motion, but as the disturbance dies out at any given station or as it radiates the periods of these two sets of vibrations approach each other. (p. 29.)

6. Maximum Velocity and Intensity of Movements.

1. An earth particle usually reaches its maximum velocity during the first inward movement (p. 32.) A high velocity is however sometimes attained in the first outward semi-oscillation. (pp. 32. 33.)
2. The intensity of an earthquake is best measured by its destructive power in overturning, shattering or projecting various bodies. (p. 35.)
3. The value $V^2 = \frac{4}{3} g \sqrt{a^2 + b^2} \times \left(\frac{1 - \cos \theta}{\cos^2 \theta}\right)$ used by Mallet and other seismologists to express the velocity of shock as determined from the dimensions of a body which has been overturned, is a quantity not obtainable from an earthquake diagram. It represents the effect of a sudden impulse. (pp. 58. 69. 74.)
4. In an earthquake a body is overturned or shattered by an acceleration f which quantity is calculable for a body of definite dimensions.

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The quantity f as obtained from an earthquake diagram lies between $\frac{V}{t}$ and $\frac{V^2}{a}$, where V is the maximum velocity, t is the quarter period and a is the amplitude (pp. 35. 74.)

5. The initial velocity given in the formula $V^2 = \frac{2a^2}{b}$ (for horizontal projection) used by Mallet as identical with V^2 in 3, are not identical quantities.
   The velocity calculated from the range of projection when projection occurs is identical with the maximum velocity as measured directly or calculated from a diagram. (pp. 70. 71. 72.)
6. In discussing the intensity of movement I have used the values $\frac{V^2}{a}$.
7. The intensity of an earthquake at first decreases rapidly as the disturbance radiates, subsequently it decreases more slowly. (p. 61.)
8. A curve of intensities deduced from observations at a sufficient number of stations, would furnish the means of approximately calculating an absolute value for the intensity of an earthquake. (p. 37.)

7. Vertical Motion.

1. In soft ground vertical motion appears to be a free surface wave which outraces the horizontal component of motion. (p. 40.)
2. Vertical motion commences with small rapid vibrations and ends with vibrations which are long and slow. (p. 29.)
3. High velocities of transit may be obtained by the observation of this component of motion. It is possibly an explanation of the preliminary tremors of an earthquake and the sound phenomenon. (p. 41.)
4. For amplitude and period of vertical waves as observed at the same or different stations see (p. 28. and diagrams.)

8. Velocity.

1. The velocity of transit decreases as a disturbance radiates. (pp. 40. 50. 56.)
2. Near to an origin the velocity of transit varies with the intensity of the initial disturbance. (pp. 40. 50. 56.)

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3. In different kinds of ground, with different intensities of initial disturbance, and with different systems of observation I determined velocities lying between 630 and about 200 ft. per second. (First, fourth, fifth and sixth experiments.)
   Mallet determined a velocity in sand of 824 ft. and in granite of 1664 feet per second. General Abbot has observed velocities of 8800 feet per second. All of these determinations I regard as being practically correct. The great difference between them being due, partly to the nature of the rock, the intensity of the initial disturbance, and the kind of wave which was observed.
4. In my experiments the vertical free surface wave had the quickest rate of transit, the normal being next and the transverse motion being the slowest. (pp. 40. 50.)
5. The rate at which the normal motion outraces the transverse motion is not constant. (p. 38.)
6. As the amplitude and period of the normal motion approach in value to those of the transverse motion, so do the velocities of transit of these motions approach each other. (p. 40.)
   That the ratio of the speed of normal and transverse motions is not constant is shewn from a table of these velocities calculated for different rocks from their moduli of elasticity (p. 75.)

9. Miscellaneous.

1. At the time of an earth disturbance currents are produced in telegraph lines. (p. 54.)
2. The exceedingly rapid decrease in the intensity of a disturbance in the immediate neighbourhood of the epicentrum is shewn by the diagram on (p. 61.)
3. For the duration of a disturbance due to a given impulse in different kinds of ground, reference must be made to the detailed descriptions of the first four sets of experiments.
4. Many of the results enunciated above find direct or indirect confirmation in experiments others than those to which reference has been made.

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NOTE ON PROF. EWING'S DUPLEX PENDULUM SEISMOMETER WITH EARTHQUAKE RECORDS OBTAINED BY IT.

BY

K. SEKIYA.

[READ OCT. 13TH 1884.]

This is another form of the Duplex Pendulum Seismometer designed by Prof. Ewing just before he left this country in June 1883. Its principle as well as its kinetic condition is the same as that described in the Transactions of this society. Vol. V. The chief object of the form now suggested is to make the instrument more simple and thus fit it for wide use.

Neutral or feebly stable equilibrium, the requisite condi- into for seismometers, is here obtained by combining a common pendulum A which is stable with an inverted unstable pendulum B. The upper or common pendulum is a circular disc of lead and is hung by three silk threads *t* from the top of a wooden tripod frame 3½ ft. high. Three wooden screws *c* at the top allow the length and the level of the pendulum bob to be adjusted. The lower or inverted pendulum is also a circular disc of lead and is supported by a single brass tubular rod whose conical point rests in the agate cup fixed in the wooden base plate. The upper and lower pendulums are connected by a ball and tube joint. A small spherical ball projecting from the upper side of the lower bob accurately but smoothly fits into a vertical tube fixed through the centre of the upper bob. This jointed system has horizontal freedom to move in any azimuth and forms a neutral or feebly stable pendulum whose period of oscillation may be made as slow as we please. A gimbal or universal joint J is carried by the bracket firmly fixed to one leg of the tripod and forms the fulcrum of the indicating pointer. The lower end of the indicating pointer terminates in a ball and easily fits into the before mentioned tube in the upper bob just bove the point where the contact of two pendulums is

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made. This point is calculated as the steady point of the system. The upper end of the indicating pointer is a stiff straw with a marking pointer hinged at the top. The end of the marking pointer is furnished with a steel point and rests upon a smoked glass plate on which the earthquake records are to be written. The ratio of the distances from the fulcrum J to the lower and upper ends of the indicating pointer is 1 : 4.4 and therefore the instrument magnifies the motion of the ground 3.4 times. The base plate is furnished with three levelling screws by which the level of the instrument may be adjusted. These screws act as the feet of the instrument and rest in V grooves cut upon the face of a low stone column. The total cost of the instrument is little more than six yen.

This instrument has been set up in the earthquake Laboratory in Tokio Daigaku and has given a number of records some of which we give as examples. Almost all the records obtained indicate the characteristics of earthquake motion. At the first part of the earthquake the pointer oscillates forward and backward nearly in straight lines showing a certain decided direction of motion but gradually it begins to describe loops or sometimes figures of eight. This degeneration of backward and forward motion into loop motion is likely due to the occurence of transverse waves which combined with simultaneous normal waves may produce such results.

Fig. 1. Earthquake Oct. 5th 7.34 A.M. 1884 the diagram indicates the principal movements of the ground to have been in E and W direction with maximum amplitude of 1^{mm}.

Fig. 2. Oct 6th 10. 22. 15 A. M. 1884. The earthquake consisted of series of small movements all in E and W direction, the largest displacement being not more than 0.7^{mm} in amplitude.

Fig. 3. Nov. 23rd 10. 55. A.M. 1884. The diagram indicates motions in all directions but the first movements occurred chiefly in NE and SW. The largest displacement was 2.7^{mm}. These were fol-

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lowed by transverse motions, the combination of which with the former produced the loops and figures of eight.

Fig. 4. Nov. 29th 8. 10. 38 A.M. The direction was dicidedly E and W. The maximum amplitude was 1.5^{mm}.

Fig. 5. Dec. 1st. 8.13 A.M. 1884. The record gives the motions in all directions. The principal movements were however E and W while they were intersected in transverse directions by many disturbances. The maximum motion appears to be 2.6^{mm}.

Fig. 6. Jan. 3rd 2.52 A.M. 1885. At the beginning of the earthquake the direction of motion was chiefly NW and SE, but the largest motion was transverse to this in NE and SW, the maximum amplitude being 2^{mm}.

These records when compared with those obtained on a revolving glass plate by a more elaborate instrument agree very well in their main features.

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NOTES ON THE METEOROLOGY OF JAPAN.

BY

E. KNIPPING.

[READ JUNE 19th 1884.]

The following notes are based upon data obtained from twenty-three meteorological stations in Japan during the year 1883, the extreme positions being Kagoshima and Nagasaki in the south and Sapporo and Nemuro in the north. For three stations, namely, Hiroshima, Miyako and Nemuro, the records extend only over part of the year.

The mean temperature for the year 1883 ranged from 16.7° C. (62.6 Fahr.) at Kagoshima to 6.5° C. (43.7 F.) at Sapporo. The decrease with the latitude amounted to about 0.9° C. for each degree of latitude. The rate is one of the largest known, being exceeded in Europe only by the rate in the meridian of the Sea of Azow 1.0° C., while in central Europe and Britain it is 0.4° C. only. Nobiru, in 38 degrees latitude, has the same mean temperature as Cork and Valencia, in 52 deg. latitude, the advantage on the side of a great part of Britain amounting to 14 degs. of latitude, being equivalent to the difference of the north cape of Yezo and the South cape of Kiushu.

At Miyasaki in Kiushu the coldest month in 1883 was December; elsewhere in Kiushu, Shikoku, the Inland Sea, and the country round Owari bay, January; in the rest of Nippon and Yezo, February: the hottest month being August. The difference of mean temperature in February and August ranged from 19° C. (34.2 F.) at Miyasaki, 20° C. (36.0 F.) on the south coast to 28° C. (46.4 F.) at Sapporo; increasing with the latitude and distance from the sea. At Shanghai the corresponding average range of temperature is 25° C. (45.0 F.), at Peking 31° (55.8 F.), at Irkutsk 39° (70.2 F.), while in the Shetlands and in south Ireland it is only 8° C. (14.4 F.) 11° (19.8 F.) at Glasgow, 14° C. (25.2 F.) at Camden. The

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annual variation in 1883 in Japan was thus more than double the amount for Britain.

The daily variation of temperature (mean monthly maximum less minimum temperature) was in February lowest along the west coast from Shimonoseki 5° C. (9.0 F.) to Niigata 6° C. (10.8 F.), increasing with the latitude and distance from the sea, reaching the greatest amount 12° C. (21.6 F.) at Akita and Sapporo. In August the figures varied from 7° C. (12.6 F.) at Kochi, Shimonoseki and Niigata to more than 12° C. (21.6 F.) at Kioto and Sapporo, the increase depending more on the distance from the sea than the latitude. The highest temperature recorded in 1883 at any station was 36.6° C. (97.88 F.) at Wakayama; the lowest—22.2° C. (—7.96 F.) at Sapporo. The difference between the highest and lowest record at one and the same station was 36° at Kochi, (64.8 F.) 56° C. (100.8 F.) for Sapporo. Changes of 14 and 15° C. at one station in 24 hours are not unfrequent in the spring and autumn.

All stations, regarding temperature for the latitude, show for January a large deficit, from to 4° to 7° C., (7.2 to 12.6 F.) Numazu the smallest; most stations for July 1883 a slight excess, Wakayama 2° C. (3.6 F.); however Miyasaki, the east coast and Tsugaru strait show in July also a deficit, amounting to 2° (3.6 F.) at Miyako and Hakodate.

In winter the differences of pressure in Japan were exceedingly great, decreasing from S. W. to N. E. If we take December 1883, for instance, we have 767 millimetres (inches 30.197) pressure in Kiushiu and Shikoku, 755 mm. (29.724) at Nemuro, or a rate of 0.9 mm. (0.035) for each 60 nautical miles, one of the greatest rates known. Accordingly we have in winter generally strong west winds, much snow and clouded sky on the weather shore, north-west and west coast; clear weather and little snow on the lee shore, south and east coast. In summer the pressure over Japan shows only slight differences, 1 to 3 mm. (0.039 to 0.107); decreasing towards the west, and mostly light southerly and easterly winds.

Least rain fell in 1883 in Yezo, at Awomori, Nobiru and in the Inland Sea, less than 1 metre (39.37 inches); most in

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Kanazawa, 2.4 m. (94.49 inches), and in Kiushu and Shikoku. In January, February, November and December the north-west and west coast show the greatest fall; in March; the distribution, is, however, more equal. In April, May and June Kiushu and Shikoku show the highest record; July and August were dry, except heavy downpours during typhoons; 171 mm. (6.73 inches) on August 18th at Nagasaki, 162 mm. (6.38 inches) at Kochi on the 20th. September and October show a more equal distribution over all stations.

The geographical position of Japan between the two greatest areas of land and water in the world makes its climate dependent on these two great factors. The connection between temperature and pressure is such, that where the temperature is comparatively too high the pressure is low, and where the temperature is too low, the pressure is high. In Siberia in January temperature is 20° C. (36.0 F.) too low for the latitude, the pressure as high as 778 mm. (30.630), while at the same time near Alaska in the North Pacific temperature is 14° (25.2 F.) too high, pressure as low as 752 mm. (29.606.) The flow of air being from high to low, and the powerful upper currents being always from the W. our winds in winter are W., strong; all depressions march with the wind towards the east without interruption, and easterly gales are rare. In July the position is almost reversed but not so marked as in January. Temperature in Central Asia is then 8° C. (14.4 F.) too high, pressure at 750 mm. (29.527); in the North Pacific 6° C. (10.8 F.) too low, pressure at 766 mm. (30.157). Thus in winter differences of 34°C. (61.2 F.) and 26 mm. (1.023) are at work, in summer 14° C. (25.2 F.) only and 16 mm. (0.629). Thus the prevailing winds in summer should be south and east, light, the depressions march to the north and west, but their progress is comparatively slow, as they are not carried on by the upper currents. The march and progress of the depressions, on which the weather depends, is connected with the gradual formation, disappearance and reversal of these areas of high and low temperature and pressure.

The law connecting both invites an application with

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regard to February 1883, in which, judging by January and March, an abnormal distribution of pressure appears to have taken place. Pressure was too high in the whole east and north of Japan, the line from highest to lowest pointing about south-east; temperature should have been thus also too low, and a comparison shows actually that February 1883 was the coldest out of a period of 7 years in Tokio, 8 in Sapporo, 7 in Hakodate and, 3 years for several other stations.

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THE CECCHI SEISMOGRAPH. A NEW MODEL CONSTRUCTED FOR THE OBSERVATORY OF MANILLA.

(Translation of a paper received from Father Federico Faura S. J. of Manilla.)

BY

DR. F. DU BOIS.

[READ JAN. 26TH 1885].

All the parts composing this seismograph are collocated on a large marble tablet solidly placed upon a substructure so constructed as to prevent all oscillations save those which are truly seismical. The lower edge is 50 centimeters from the ground and the surface is perfectly perpendicular.

On the surface of this marble slab are attached five different machines which when combined or acting together compose the new apparatus and give automatically *1°* warning, *2°* time, *3°* directions and *4°* intensity. These five machines are,

First a steel spiral with its weight (M) which puts in motion the whole apparatus.

Second a clock which gives *warning*, the *time* of the shock and *puts in motion* the roll of smoked paper.

Third the horizontal pendulum (P) which describes the oscillation on the smoked paper.

Fourth the vertical pendulum (S) which describes its own oscillation.

Fifth the cylinders (C C') for unrolling the smoked paper

The clock is fixed on the highest part of the slab and governs all the apparatus. To its right stands the motor apparatus (M) to its left the horizontal pendulum (P). Below this are the cylinders for running off the smoked paper. To the side of the larger of these two and right under the clock is the vertical pendulum.

The Motor apparatus (M) is composed of a weight of lead (*m*) suspended by a strong steel spiral. From the said weight

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a silk thread passes upward through the spiral and over a pulley (*c*) to a small brass spiral (*o*) which serves as a counter weight and keeps the pulley in place.

From the center of the pulley rises an arm or lever cut almost to a knife like point (*a*). On the edge of this rests a similar point which is screwed on to the longer arm of a lever (*l*). To the opposite arm of this lever is attached a fine string (*f*) which goes downwards to be attached to the middle lever (*i*) and to the left of its fulcrum. So as to enable both the knife like edges at (*a*) to rest upon each other exactly, the counter spiral (*o*) must be properly regulated which is done by moving the screw which controls it.

The weight of this horizontal and vertical pendulum has on its under side a tube of brass (*t*) which can be elongated. Over the aperture of this, a piece of fine unstarched linen is stretched. This piece of linen is punctured by the superior external horn of a brass ring (Fig. 3) which brass ring by means of two other interior projections one from above the other from below, rests upon a horizontal lever and again this same brass ring by means of another external projection down wards rests upon the extremity of the screw (*v*). Both this screw and the horizontal lever (*r*) are moveable in order that the ring may be placed in a position vertical to the horizontal pendulum. At the extremity of this last lever is attached a third little silk thread (*f''*) which is united also with the intermediary lever to the right of the fulcrum.

Against the extremity of the long arm of the intermediary lever rests a small brass plate (*n*) to the extremity of which is attached a thread (*f'''*) which passes behind a fixed "point" to which the plate is attached and is prolonged as far as the lever of the clock (O) and operates upon the balance wheel of the same.

The time weight (P) runs between four iron wires in order to prevent interference with other pieces of the seismograph.

The cord of the weight causing the clock to strike passes around a pulley just above the great cylinder C, then around another pulley behind the great cylinder C and comes down to

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the weight (p'). On this cylinder are three springs or regulators by means of which the paper is kept in place.

The paper thus rolls from the big cylinder and over small one (C') and is held in place and tightly drawn by the weight of two nippers made for this purpose.

On the left of the clock is attached the horizontal pendulum with a kind of universal joint. (Fig. 2).

The weight of this pendulum has above it a disc of brass covered with smoked paper. Working on this there is an ivory point fixed to a very light and balanced lever which moves upon a little arm (b) fixed to the marble slab.

Below the weight is attached still another lever similar to the preceding one the point of which rests on the smoked paper which rolls on the cylinder.

Below the clock and alongside the cylinders stands the sussultory pendulum consisting of a weight which rests between the prongs of a fork the other extremity of the fork being attached to a fixed point. The weight and the fork are suspended by a spiral (s') attached to a fixed point above. Above the spiral there is a shaft bearing a pulley (c'). A vertical prolongation is attached to this shaft and a horizontal piece hinged to a fixed point is attached to the lower end of it. One end of this rests on the smoked paper. By this means a lateral motion on the paper corresponds with a vertical motion of the pendulum (m'). In order to put the instrument in readiness to work it is necessary.

(1) Place the inferior point of the ring (2) on the point (v)
(2) Place the blades of the superior lever one above the other.
(3) Lay the brass table (n) on the intermediary lever (1) in order to keep the system of wheels of the clock in statu quo
(4) Blacken the paper and adjust the three points in contact with the same.

In order to blacken the paper it is necessary to take off the weight of the clock and lift up all the writing points.

The paper is then all wound upon the great cylinder—then slowly unwound while a light affording smoke is placed

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beneath. When all the paper is smoked it is wound on the big cylinder again.

Every thing being in order if there is a horizontal motion, at the least shock, the motor pendulum throws off the vertical the ring (3) which no longer having its point of rest on the point of the screw (*v*) falls by its own weight and lowers, the lower lever (*m*) to which its is united. The lower lever by means of the thread draws down intermediate lever (*i*) and the little table (*n*) which rested upon it falls and sets free the works of the clock. The hands of the clock then move, the clock rings, the bell weight descends and moves the cylinder and the paper rolls off.

At the same time the undulatory pendulum moves and the point attached to it traces on the paper all the movements to which the pendulum is subjected.

These motions are also recorded on the circular smoked paper placed above the weight of the same pendulum.

If the motion had been sussaltory and the point placed on the screw (*v*) did not move, then the apparatus would be put in motion by means of the upper part. At the first oscillation of the pendulum the little sping (*o*) would force the pulley (*c*) to rotate.

This would put the lever out of equilibrium and by its connection with the intermediary lever, again the clock would be started.

If the shock were vertical and the big pendulum did not move, the apparatus just under the clock will be brought into play. As the weight rises and falls the little string attached to it will turn the pulley. This rotates the shaft and the point which is fixed to it will record on the paper the vertical motion of the pendulum (*m'*).

After a shock it is necessary to put everything back to its original position in order to have the apparatus in readiness for a second shock.

The smoked paper is removed and fresh paper is put in its place and the operation of smoking has to be done again.

The irregular marks upon the paper are due to oscillations of the earth and indicate direction and the intensity.

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Motions with a gradually decreasing amplitude are due merely to the normal oscillation of the pendulum acquired by the shock.

The curves which may be found traced upon the disc above the pendulum serve to indicate at first sight the direction of the shocks and their intensity—while the paper below which unrolls enables us to see all the phases of the phenomena in all its various movements.

The observer should note the relative time which the horizontal and vertical pendulum take in oscillating in order to establish the just relation between the two movements as written on the paper.

In order to blacken the little paper above the weight it is only necessary to turn it toward the light and pass the lamp forward and backward till it is black enough.

The direction of the meridian may be marked upon the diagram.

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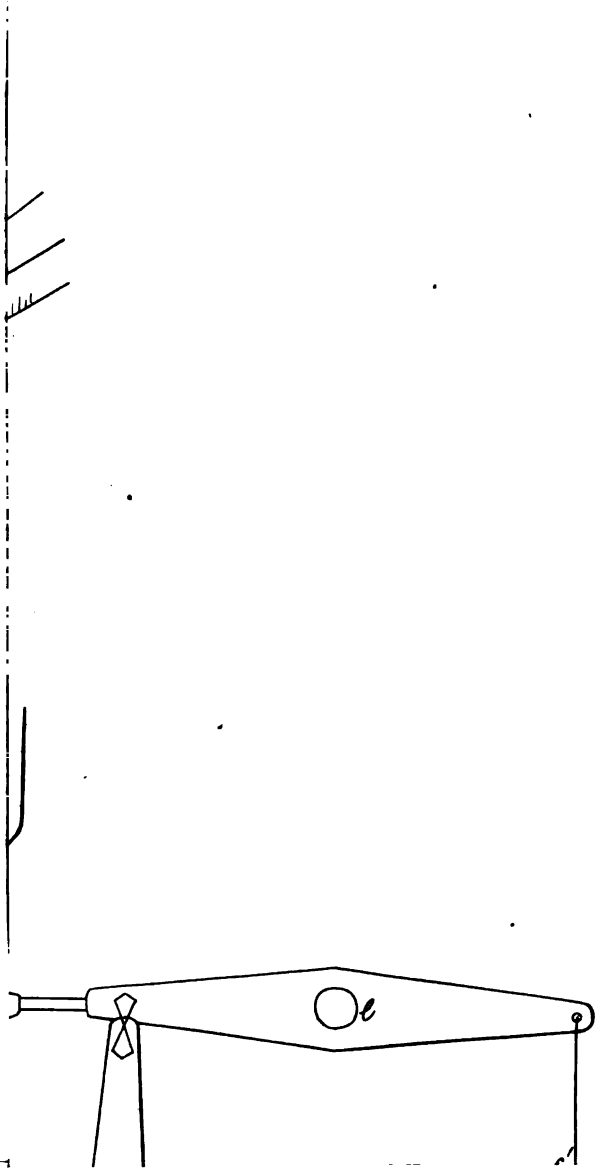

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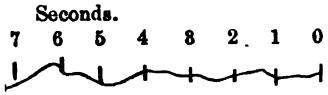

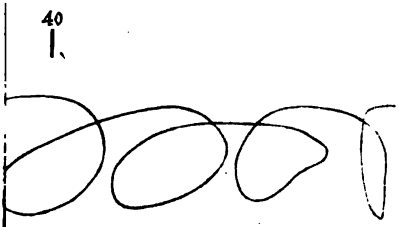

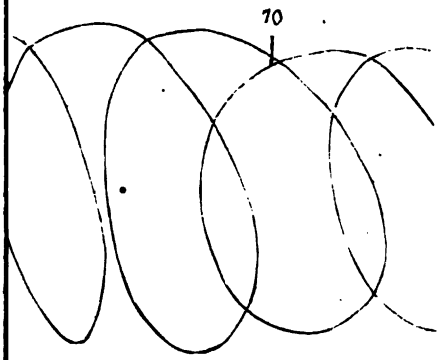

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FARTHER NOTES ON THE EARTHQUAKES OF ISCHIA

BY

DR. F. DU BOIS.

[READ JAN. 26TH 1885]

In the Bolletino del R. Comitato Geologico d'Italia for 1883 appears an article on the Ischian earthquake of that year by the engineer L. Baldacci. The present paper is an epitome and review of the same.

The oldest geological soil of the island is the light green *tufa* of Epomeo this being an agglomerated and agglutinated mass of ashes in which are often found materials of non volcanic origin, mineral, animal and vegetable.

On this tufa there are very extensive deposits of a peculiar product due to the decomposition under the sea of the tufa itself, which product occasionally passes into plastic clay adapted to the manufacture of tiles.

Casamicciolo rested on this product of decomposition while Lacco is situated partly on the trachyte (*trachyte lava*) and partly on the original tufa of Epomeo. Forio, Fontana, Serrara &c. are built exclusively on the tufa.

Noting the position of the mineral springs and other volcanic manifestations of the island it is concluded that there exists on the north of the island a great curved fissure through which all these springs and other manifestations find their way to the surface—this curved fissure extending from the baths of Ischia to Forio passing exactly through Casamicciola, its convexity turned to the north.

Now if we examine the other principal manifestation going from N—S we find a series of thermal springs indicating a fracture running from N.N.W—S.S.E crossing the first exactly at Monte Cito almost under the town of Casamicciola.

He believes that there are two fractures and not the meeting of a fracture and the lip of the old submarine crater

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as Rossi would have it, because the manifestations along both are the same and also because it is better to attribute them to the same cause than to seek out a hypothesis which can not be demonstrated.

The result of his observations has been that houses built on the trachyte at Lacco Ameno and at Monte Zale suffered infinitely less than those built on the tufa of Epomeo or on the clay, which was the result of the decomposition of the tufa. Casamiciola was almost exclusively built on this clay and it can be said without exaggeration that not one stone rested upon another. Forio was built on the tufa and even of this town very little remains standing. At Lacco the houses and walls which were built on the trachyte offered a much greater resistance to the shock while those built on the tufa were destroyed. This agrees completely with the theory of Mallet who says "A seismical wave passing suddenly from an unelastic to an elastic soil as for instance from tufa into trachyte will not only change its velocity but also its direction, one part being reflected and another refracted." The seismical wave being thus sent backwards produces a shock in the opposite directions causing great dammage to the buildings. At the same time shocks are attenuated when they reach the more elastic soil such as granite or trachyte. This might explain why the town of Ischia felt the shock so little, being separated from the main fissure by the masses of trachyte lava from Mt. Rotaro, Mt. Montagnone and that of Arso which absorbed most of the energy of the seismical wave.

He attributes all these seismical manifestations in Ischia at the present moment, to a wakening up of the residual volcanic activity of Epomeo. He says "the opinion of Palmieri does not seem to me demonstrable that the intensity of the shock should be attributed to the existence of large caverns precisely under Casamiciola and to the falling in of the columns which sustain the vaults—the falling in being caused by an earthquake and facilitated by the subterranean circulation of thermal waters." There are it is true in the neighbourhood of Casamiciola excavations of plastic clay but I am not sure it is of these the illustrious professor is speaking. Such a cause

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indeed would be too small to produce such portentous effects and a seismical commotion propagated to so great a distance.

During his first visit he could not visit the interior of these excavations there being no one to serve him as guide, but in the latter part of August he paid a second visit to the island in order to make an examination of the excavations of plastic clay both in Casamicciola and in its neighbourhood.

In the very town of Casamicciola in the street La Faunina existed very important clay excavations which have been worked up to within three or four years. These works had a certain importance if we may judge from the numerous traces remaining of the mouths of shafts and tunnels which are to be seen. Unfortunately there apertures have been obstructed a long time back and its is absolutely impossible to gain access into the interior but *it is certain* that they must already be filled up considering on the one hand the nature of the ground which is clay with a natural tendency to swell and on the other the nature of the tunnelling which was in small sections.

The clay is extracted through little wells 20 to 30 feet in depth, these pits being dug through the overlying tufa until they meet the clay and in this clay galleries of different shapes and sizes are preforated in various directions, the elay thus extracted being drawn out by hand machines.

Besides it is undeniable that neither in the neighbourhood of these apertures nor within the perimeter of the excavations is there any trace of a falling in of the ground.

At the time of the earthquake they were working the clay in several other places, south of Casamicciola between the village and Epomeo, eastward on the lower slopes of Mt. Tabor. Unforunately the excavations south of Casamicciola could not be entered as their openings had been completely covered by landslides. The only excavations he could see were those lying to the east of Casamicciola. Owing to the nature of the ground, trachyte lava lying upon trachyte tufa, the openings into the excavation have sustained but little dammage and the works are accesible.

Accompanied by workmen he visited the most important

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of these excavations. The workmen had not been there since the catastrophy as could be seen from the tools lying around. The openings which have been worked through the trachyte tufa in order to arrive at the clay are narrow low and tortuous. Some are more than 60 meters in length and descend into the mountains some 20—30 meters below the opening. The clay is excavated in small sections because that part of the bank of clay which can be utilized is not very extensive. It was evident that everything had remained intact in the interior and had not received the least dammage from the earthquake

This is not the first instance in which seismical shocks having produced great dammage at the surface have passed absolutely unperceived at a certain distance underneath.

One can therefore reasonably conclude so far as regards the old excavations which stood in the very town itself, that they could not have constituted a danger since having been abandoned for several years they must necessarily from the nature of the material have filled themselves up again under the influence of water and pressure. Any one who is conversant with mining and working galleries knows the disastrous effects of swelling clay. But even allowing that they were not filled up there could have been no falling in as is proved from the fact of there being no evidence of this on the surface. The excavation to the south of Casamiciola and those on Mt. Tabor are too distant to have been the cause of any dammage. Besides so far as the first are concerned although the mouths are covered and we can not enter them, we may reasonably conclude that they are in the same condition as those on Mt. Tabor, the only difference being in the nature of the overlying ground, the loose tufa in the one case having slid down and obstructed the openings, the trachyte on the other hand having remained in place.

He draws the following conclusions.

I—No other cause need be sought than the volcanic activity which still remains in the island and which wakes up at intervals.

II—That this volcanic activity manifests itself along two principal fissures. One with its convexity to the north

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and extending from the Baths of Ischia to Forid, and the other in a line directed approximately from N. N. W.—S. S. E. between Lacco and the stupe of Testaicio.

III—That Casamiciola stood precisely at the intersection of these two fissures and hence at the center of the seismical focus and that it always has been and always will be the spot most devastated by earthquakes.

IV.—Finally that houses built on the trachyte lava present a much superior resistance to the shocks than those built upon tufa or upon clay and that this circumstances should be taken account of when time for rebuilding comes.

Like every one else who has written about Ischia this delegate from the corps of mining engineers has his theory. The paper however is a very unsatisfactory one. The observations are not searching, but such as they are he uses them to jump at conclusions, forgetting that he is not infallible. Whether he is right or wrong I do not know, but his facts do not warrant his inferences.

It is worthy of remark however that in the excavations where he did enter he found no evidence of the least shock and notices the fact that seismical shocks have often produced great dammage at the surface while they have passed absolutely unpereeived at a certain distance underneath. This aspect of the case opens a wide field for inquiry, and I believe that Prof. Milne had already instituted experiments in this direction with very remarkable results which he will soon publish.

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CATALOGUE OF EARTHQUAKES.

July 1883 to end of February 1885. The observations were made at The Imperial Meteorological Observatory (Chiri Kioku) by Palmieri's Seismograph.

(For first portions of this Catalogue see Trans. Seis. Soc. Vol. II pp. 3—39. Vol. VI pp. 32—35.)

No.	Month	Date	Time	Force	Direction	Duration
498	VII	28	about 2^h 25^m A.M.	—	—	—
499	VIII	17	2^h 38^m 41^s P.M.	—	—	0^m 24^s
500	X	4	3^h 8^m 11^s A.M.	7°10′	N or S	0^m 33^s
				4°40′	NW or SE	
				6°0′	W or E	
				4°0′	SW or NE	
501	XI	26	8^h 47^m 27^s P.M.	—	—	—
502	,,	27	4^h 28^m 00^s A.M.	8°50′	N or S	0^m 49^s
				2°50′	NW or SE	
				8°10′	W or E	
503	,,	30	4^h 29^m 21^s A.M.	2°20′	N or S	0^m 25^s
				1°20′	NW or SE	
				1°10′	W or E	
504	XII	4	2^h 38^m 29^s P.M.	0°50′	NW or SE	—
				1°30′	W or E	
				1°30′	SW or NE	
505	,,	20	4^h 22^m 28^s P.M.	—	—	—
506	,,	22	6^h 54^m 00^s P.M.	1°40′	NW or SE	—
507				1°30′	W or E	
508	,,	25	4^h 55^m 30^s P.M.	2°00′	N or S	
				1°00′	NW or SE	—

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No.	Month	Date	Time	Force	Direction	Duration
				1°00′	W or E	
				1°00′	SW or NE	
	1884					
509	I	2	1^h 19^m 59^s P.M.	11°10′	N or S	about 3^m
				15°30′	NW or SE	
				28°00′	W or E	
				16°25′	SW or NE	
510	,,	4	2^h 16^m 58^s P.M.	—	—	—
511	,,	10	9^h 00^m 51^s P.M.	4°05′	N or S	
				4°10′	NW or SE	
				4°40′	W or E	
				4°50′	SW or NE	
512	,,	20	0^h 53^m 34^s A.M.	4°00′	N or S	48^s
				2°00′	NW or SE	
				5°10′	W or E	
				5°30′	SW or NE	
513	,,	,,	7^h 51^m 41^s P.M.	—	—	—
514	II	22	6^h 16^m 4^s A.M.	1°10′	N or S	
				0°20′	NW or SE	
				2°00′	W or E	
				0°20′	SW or NE	
515	,,	23	about 2^h 40^m A.M.	2°40′	W or E	
				1°30′	SW or NE	—
517	III	1	about 9^h 05^m P.M.	—	—	—
518	,,	7	about 1^h 02^m P.M.?	—	—	—
519	,,	14	4^h 50^m 00^s A.M.?	—	—	—
520	,,	,,	about 7^h 10^m 00^s A.M.	—	—	—

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No.	Month	Date	Time	Force	Direction	Duration
521	III	14	8h 56m 25s P.M.	—	—	—
522	,,	15	8h 24m 33s P.M.	—	—	20s
523	,,	17	9h 03m 21s P.M.	1°50′	W or E	—
524	,,	31	8h 22m 00s P.M.	0°40′	NW or SE	—
				1°40′	W or E	
				1°20′	SW or NE	
525	IV	4	9h 34m 03s P.M.	0°10′	W or E	—
526	,,	6	0h 23m 00s A.M.	5°00′	N or S	1m 00s
				3°00′	NW or SE	
				3°10′	W or E	
				2°10′	SW or NE	
527	V	6	5h 37m 37s P.M.	3°20′	N or S	1m 04s
				2°40′	NW or SE	
				3°10′	W or E	
				4°00′	SW or NE	
528	,,	6	9h 00m 21s P.M.	3°00′	N or S	30s
				1°30′	NW or SE	
				1°30′	W or E	
				2°50′	SW or NE	
529	,,	11	9h 45m 27s P.M.	9°00′	N or S	about 1m 50s
				8°50′	NW or SE	
				6°30′	W or E	
				4°10′	SW or NE	
530	,,	12	8h 23m 47s A.M.	0°10′	N or S	
				2°10′	NW or SE	
				1°10′	W or E	
				2°20′	SW or NE	

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No.	Month	Date	Time	Force	Direction	Duration
531	V	19	$0^h\ 28^m\ 48^s$ P.M.	1°10′	N or S	about 10ˢ
				3°00′	NW or SE	
				1°50′	W or E	
				0°10′	SW or NE	
532	,,	,,	$11^h\ 34^m\ 45^s$ P.M.	0°10′	N or S	about 7ˢ
				0°40′	NW or SE	
				0°40′	W or E	
				0°50′	SW or NE	
533	,,	27	$11^h\ 10^m\ 50^s$ P.M.	2°20′	SW or NE	—
534	,,	28	$1^h\ 54^m\ 42^s$ P.M.	—	—	—
535	,,	29	$11^h\ 29^m\ 38^s$ P.M.	—	—	—
536	,,	31	$0^h\ 59^m\ 48^s$ P.M.	1°00′	NW or SE	—
				1°00′	W or E	
537	VI	11	$11^h\ 11^m\ 02^s$ P.M.	6°00′	W or E	25ˢ
538	,,	14	$3^h\ 29^m\ 19^s$ A.M.	0°20′	NW or SE	—
				0°10′	W or E	
				0°10′	SW or NE	
539	,,	15	$0^h\ 6^m\ 25^s$ P.M.	—	—	—
540	,,	18	$11^h\ 19^m\ 16^s$ P.M.	—	—	—
541	VII	18	$2^h\ 10^m\ 00^s$ P.M.	2°00′	W or E	—
542	VIII	6	$6^h\ 55^m\ 49^s$ P.M.	—	—	—
543	,,	11	$2^h\ 57^m\ 10^s$ A.M.	0°15′	N or S	—
				0°10′	NW or SE	
				1°10′	W or E	
544	,,	22	$4^h\ 05^m\ 00^s$ A.M.	—	—	—
545	,,	30	$7^h\ 24^m\ 51^s$ A.M.	—	—	—
546	IX	11	$0^h\ 42^m\ 5^s$ A.M.	2°15′	W or E	—

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No.	Month	Date	Time	Force	Direction	Duration
547	IX	21	5^h 15^m 32^s P.M.	2°00′	W or E	—
548	X	5	7^h 34^m 00^s A.M.	—	—	38^s
549	,,	6	10^h 22^m 15^s A.M.	2°20′	NW or SE	12^s
				2°10′	W or E	
550	,,	13	8^h 16^m 35^s A.M.	1°10′	NW or SE	40^s
				4°40′	W or E	
551	,,	15	4^h 21^m 54^s A.M.	12°30′	N or E	2^m 00^s
				53°40′	NW or SE	
				48°30′	W or E	
				95°10′	SW or NE	
552	,,	16	3^h 14^m 14^s A.M.	1°05′	W or E	about 30^s
				1°05′	SW or NE	
553	,,	17	8^h 21^m 25^s A.M.	—	—	—
554	,,	19	8^h 22^m 47^s P.M.	1°00′	NW or SE	—
				1°40′	W or E	
555	,,	24	8^h 35^m 39^s P.M.	1°20′	W or E	about 20^s
556	XI	16	9^h 51^m 34^s A.M.	2°30′	N or S	19^s
				0°20′	NW or SE	
				3°40′	W or E	
				0°10′	SW or NE	
557	,,	22	1^h 14^m 46^s A.M.	1°00′	N or S	10^s
				0°40′	NW or SE	
				3°20′	W or E	
558	,,	23	about 10^h 50^m A.M.	—	—	—
559	,,	,,	about 9^h 00^m P.M.	—	—	—
560	,,	24	about 8^h 00^m A.M.	—	—	—
561	,,	27	1^h 37^m 58^s P.M.	3°00′	NW or SE	25^s

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No.	Month	Date	Time	Force	Direction	Duration
				8°45′	W or E	
562	XI	28	2h 41m 34s A.M.	4°40′	W or E	about 1m 10s
563	,,	29	8h 10m 38s A.M.	0°30′	W or E	1m 37s
564	XII	1	8h 11m 55s A.M.	4°00′	W or E	1m 05s
565	,,	7	4h 20m 14s A.M.	1°00′	W or E	18s
566	,,	7	8h 34m 07s P.M.	4°10′	N or S	50s
				3°50′	NW or SE	
567	,,	,,	about 9h P.M.	——	——	——
568	,,	,,	about 10m P.M.	——	——	——
569	,,	9	10h 30m 56s P.M.	0°55′	SW or NE	47s
570	,,	10	5h 44m 02s A.M.	——	——	about 25s
571	,,	,,	7h 33m 55s A.M.	——	——	——
572	,,	15	2h 16m 34s A.M.	1°00′	W or E	7s
				1°50′	SW or NE	
573	,,	16	8h 31m 9s P.M.	2°30′	N or S	1m 00s
				8°30′	NW or SE	
				5°30′	W or E	
				4°40′	SW or NE	
574		22	10h 34m 1s A.M.	3°30′	N or S	25s
				2°10′	NW or SE	
				2°10′	W or E	
				2°00′	SW or NE	
575	,,	23	9h 06m 42s A.M.	3°00′	W or E	26s
				2°50′	SW or NE	
576	,,	25	9h 59m 29s P.M.	——	——	——
577	,,	27	4h 28m 47s P.M.	——	——	——
578	,,	30	1h 4m 41s A.M.	6°00′	N or S	49s

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No.	Month	Date	Time	Force	Direction	Duration
				6°00′	NW or SE	
				4°30′	W or E	
				5°20′	SW or NE	
	1885					
579	I	8	2^h 31^m 53^s A.M.	0°50′	N or S	1^m 20^s
				0°50′	NW or SE	
				2°55′	W or E	
				3°00′	SW or NE	
580	,,	8	10^h 27^m 45^s A.M.	0°45′	N or S	50^s
				0°35′	NW or SE	
				0°30′	W or E	
				0°10′	SW or NE	
581	,,	15	after 9^h P.M.	—	—	—
582	,,	17	10^h 13^m 39^s A.M.	0°40′	N or S	5^s
				0°10′	W or E	
				1°00′	SW or NE	
583	,,	17	11^h 20^m 41^s P.M.	0°25′	N or S	—
				1°00′	NW or SE	
				2°00′	W or E	
				0°10′	SW or NE	
584	,,	24	9^h 20^m 04^s A.M.	2°20′	N or S	16^s
				2°40′	NW or SE	
				3°40′	W or E	
				2°20′	SW or NE	
585	,,	31	11^h 54^m 8^s P.M.	1°00′	N or S	1^m 24^s
				0°40′	NW or SE	
				2°10′	W or E	

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No.	Month	Date	Time	Force	Direction	Duration
				4°20′	SW or NE	
586	II	2	4^h 8^m 11^s P.M.	2°30′	N or S	5^s
				1°50′	NW or SE	
				2°20′	W or E	
				10°00′?	SW or NE	
587	,,	4	7^h 52^m 7^s P.M.	1°20′	N or S	43^s
				0°20′	NW or SE	
				2°10′	W or E	
588	,,	6	9^h 40^m 27^s A.M.	0°30′	N or S	4^s
				0°10′	SW or NE	
589	,,	,,	1^h 34^m 57^s P.M.	10°40′	N or S	57^s
				8°40′	NW or SE	
				7°00′	W or E	
				2°50′	SW or NE	
590	,,	9	2^h 03^m 40^s A.M.	4°20′	N or S	—
				2°50′	NW or SE	
				3°00′	W or E	
				1°00′	SW or NE	
591	,,	12	2^h 56^m 58^s P.M.	7°20′	N or S	1^m 58^s
				8°20′	NW or SE	
				10°00′	W or E	
592	,,	19	after 4^h A.M.	—	—	—
593	,,	27	1^h 37^m 29^s P.M.	1°30′	N or S	20^s
				2°00′	NW or SE	
				2°00′	W or E	
594	,,	28	10^h 20^m 05^s P.M.	2°50′	N or S	—
595	III	8	after 7^h P.M.	0°10′	N or S	—

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No.	Month	Date	Time	Force	Direction	Duration
				1°00′	NW or SE	
				0°30′	W or E	
				0°10′	SW or NE	
596	III	12	4^h 08^m 13^s P.M.	4°20′	N or S	58^s
				3°30′	NW or SE	
				2°50′	W or E	
				1°50′	SW or NE	
597	,,	20	1^h 1^m 13^s P.M.	22°00′	N or S	1^m 14^s
				13°00′	NW or SE	
				21°00′	W or E	
				16°40′	SW or NE	
598	,,	,,	2^h 21^m 40^s P.M.	—	—	—
599	,,	23	2^h 31^m 28^s A.M.	—	—	—
600	,,	24	after 2^h A.M.	—	—	—
601	,,	27	2^h 27^m 35^s P.M.	0°50′	NW or SE	5^s
				1°30′	W or E	
602	,,	28	about 1^h 7^m A.M.	—	—	—
603	IV	7	after 2^h A.M.	—	—	—
604	,,	23	11^h 52^m 24^s A.M.	—	—	about 10^s
605	,,	24	7^h 01^m 53^s P.M.	—	—	about 36^s
606	,,	25	after 1^h P.M.	—	—	—

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SEISMOLOGICAL SOCIETY OF JAPAN.

CONSTITUTION.

[CORRECTED TO 1883 JAN. 1.]

1.—This Society shall be called the *Seismological Society of Japan.*

2.—The objects of this Society shall be the furtherance of the study of, and the collection of facts relating to all the phenomena connected with *earthquakes* and *volcanoes.*

3.—At the meetings of the Society papers on general science may be read, subject to the approval of the Society.

4.—This Society shall consist of *Corporation, Honorary* and *Ordinary* members.

5.—*Honorary Members,* who must be non-residents in Japan, shall be admitted on grounds to be determined by the Committee.

6.— } Cancelled.
7.— }

8.—The annual subscription shall be due on January 1st, and shall be, for members who receive the English *Transactions,* 8 *yen,* or £ 1., or $ 5. Japanese members who live in the interior may receive only the Japanese *Transactions,* and in that case the annual subscription shall be 4 *yen.*

9.—The Officers of the Society shall be a *President,* a *Vice-President,* a *Foreign Secretary,* a *Japanese Secretary,* a *Foreign Treasurer,* a *Japanese Treasurer* and five *Ordinary Members,* two of whom shall be residents of Yokohama. These eleven shall form the Committee, of whom four shall form a quorum. The Chairman of the Committee shall have a deciding vote.

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10.—The affairs of this Society shall be managed by the Committee, who shall also decide on the papers to be published in the *Transactions* of the Society.

11.—General Meetings, due notice of which shall be given to the Members by the Secretary, shall be held at convenient dates in Tokio or Yokohama.

12.—The Officers of the Society shall be elected each year by ballot at an Annual Meeting.

13.—The Committee shall hold a Meeting one week before each General Meeting.

14.—At the Annual Meeting the Secretary and the Treasurer shall present their Reports.

15.—Any amendments to this constitution may be proposed at any General Meeting, and shall be considered at the next, when, if two-thirds of the Members are present, it may be passed by a majority vote; if however two-thirds of the Members are *not* present, and the majority of those present are in favor of the amendment, it shall be considered at the succeeding Meeting, when, if a majority of those present are in favor of the amendment, it shall be adopted.

16.—The Secretary shall notify Members of proposed amendments to the constitution.

RULES ADOPTED BY THE COMMITTEE.

[CORRECTED TO 1883 JAN. 1.]

1.—Every paper shall be submitted to the Committee, either in full or abstract, before it is put on the list of the Society for public reading.

2.—Any person presenting a paper to the Society shall be required to state whether he intends to publish it elsewhere.

3.—Each paper shall be submitted to a sub-committee who shall have power to recommend whether it shall be printed in the *Transactions* of the Society *by title, in abstract,* or *in full.*

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4.—The printing, in the Society's *Transactions*, of remarks or criticisms upon papers read at any meeting, shall be limited substantially to what was uttered in public at such meeting; or if any new matter, in the way of further remark or criticism, is offered later, it must first be submitted to the Committee for their decision.

5.—To any new Member of the Society will be given one copy of all the volumes of the *Transactions* published after such Member joins the Society, and to any retiring Member the volumes including the papers read up to the time of such Member's resignation, if all his dues are then paid.

6.—To Members of the Society extra copies of the *Transactions* will be sold at the cost price of publication, which may be learned by application to the Secretary.

OFFICERS OF THE SOCIETY.

FOR THE YEAR ENDING

MARCH, 1883.

President—GENERAL G. YAMADA, MINISTER OF THE INTERIOR.
Vice-President—PROF. J. A. EWING.
Foreign Secretary—PROF. JOHN MILNE.
*Acting Foreign Secretary**—PROF. H. M. PAUL.
Japanese Secretary—PROF. D. KIKUCHI.
Foreign Treasurer—P. MAYET, ESQ.
Japanese Treasurer—N. KANDA, ESQ.

Members of the Committee,
- *Tokio*: I. HATTORI, ESQ.; DR. G. WAGENER.
- *Yokohama*: CAPT. F. BRINKLEY, R.A.; W. H. TALBOT, ESQ.

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* During the temporary absence of the *Foreign Secretary* in Europe.

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MEMBERS OF THE SOCIETY.

[CORRECTED TO 1883 FEB. 1]

Honorary Member.

HIS EXCELLENCY KING KALAKUA of the *Hawaiian Islands.*

Corporation Member.

The *Kayo Gakko* ..... *Gifu Ken.*

Ordinary Members.

ABELLA Y CASARIEGO, DON ENRIQUE ..... *Manila.*
ALEXANDER, PROF. T, C. E. ..... *Tokio.*
ARAI, I. ..... „
BAELZ, PROF. E., M. D. ..... „
BASSNET, THOMAS ..... *Jacksonville, Fa., U. S. A.*
BASSNET, MRS. T. ..... „ „ „
BEADON, R. J. ..... *Tokio.*
BEUKEMA, T. W., M. D. ..... *Yokohama.*
BIAGIONI, F. ..... „
BLACKISTON, CAPT. T. W., R.A. ..... „
BOLTON, PROF. H. C. ..... *Hartford, Conn., U. S. A.*
BRINKLEY, CAPT. F., R. A., EDITOR OF THE "JAPAN MAIL" ..... *Tokio.*
BROWN, A. R. ..... *London.*
BROWN, COLVILLE ..... „
BROWNE, H. St. JOHN ..... *Kobe.*
BRUSH, PROF. G. J ..... *New Haven, Conn., U. S. A.*
CARCANO, COUNT SILVIO, H. ITALIAN M. CONSUL ..... *Yokohama.*
CASATI, LUIGI ..... *Tokio.*
CHAMBERLAIN, B. H. ..... „
CHAMBERS, JOHN, C.E. ..... „
CHIOSSONE, E. ..... „
CONDER, JOSIAH ..... „
COX, W. D. ..... „
COX, PROF. E. T. ..... *San Francisco, Cal., U. S. A.*
DAN, T. ..... *Tokio.*
DIVERS, PROF. E., M. D. ..... „

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EYKMANN, DR. J. F. ..... *Tokio.*
ELDRIDGE, STUART, M. D. ..... *Yokohama.*
ELGAR, F. ..... *London.*
EWING, PROF. J. A. ..... *Tokio.*
FENOLLOSA, PROF. E. F. ..... „
FUJIOKA, PROF. J. ..... „
FUJITANI, T. ..... „
FUKUOKA, H. E. T., MINISTER OF EDUCATION ..... „
FURUICHI, K. ..... „
FUTAMI, K. ..... „
GORDON, T. W., M. D. ..... *Georgetown, Ohio, U. S. A.*
GOTO, M. ..... *Tokio.*
GOTTSCHE, PROF. C. ..... „
GOWLAND, W. ..... *Osaka.*
GRAY, PROF. THOMAS ..... *Glasgow.*
HAMAO, A. ..... *Tokio.*
HARKNESS, PROF. WM., U. S. N. ..... *Washington, U. S. A.*
HATTORI, I. ..... *Tokio.*
HAWES, LIEUT. A. G. S., R. M. ..... „
HEGT, M. J. B. N. ..... *Yokohama.*
HOLTHAM, E. G., C.E. ..... *London.*
IRWIN, R. W. ..... *Tokio.*
ISAWA, S. ..... „
IWASA, PROF. I. ..... „
JAMES, LIEUT. J. M. ..... *Shinagawa.*
JUDD, PROF. J.W., F. R. S. ..... *School of Mines, London.*
KANDA, N. ..... *Tokio.*
KATAYAMA, T. ..... „
KATO, H., PRESIDENT OF TOKIO UNIVERSITY ..... „
KIKUCHI, PROF. D. ..... „
KNIPPING, E. ..... „
KOCHIBE, T. ..... „
KORSCHELT, O. ..... „
KOZIMA, PROF. N. ..... „
KUDO, S. ..... *Sapporo.*
KUKI, R., VICE-MINISTER OF EDUCATION ..... *Tokio.*
KUWABARA, M. ..... „
LYMAN, B. S. ..... *Northampton, Mass., U. S. A.*

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McCarthy, J. W. ..... *London.*
Martin, G., M.D. ..... *Tokio.*
Martin-Lanciarez, E., H. Italian M. Chargé d'Affaires ..... „
Mayet, P. ..... „
Mendenhall, Prof. T. C. ..... *Columbus, Ohio, U. S. A.*
Milne, Prof. John ..... *Tokio.*
Miyake, Prof. H. ..... „
Mori, J. ..... „
Nakamura, K. ..... „
Nakashima, N. ..... „
Namura, T. ..... *Chiugakko, Miyagi Ken.*
Naumann, Dr. E. ..... *Tokio.*
Netto, Prof. C. ..... „
Nishi, M. ..... „
Omori, S. ..... „
Osborne, A. O. ..... *Waterville, N. Y., U. S. A.*
Palmer, Lt.-Col. H. S., R.E. ..... *London.*
Parkes, H. E. Sir Harry S., K.C.B., K.C.M.G., H.B.M. Minister, *Tokio.*
Paton, George ..... „
Paul, Prof. H. M. ..... „
Pryer, H. ..... *Yokohama.*
Rennie, Sir R. T., Chief Justice of H. B. M. Supreme Court for China and Japan .....
Ringer, F. ..... *Nagasaki.*
Rodwell, Prof. G. F. ..... *Wiltshire, England.*
Roretz, A. von, M.D. ..... *Yamagata.*
Rudler, W. F. ..... *School of Mines, London.*
Satow, E. M., 2nd Sec. and Japanese Sec. of H. B. M. Legation ..... *Tokio.*
Sekiya, K. ..... „
Shinagawa, Y., Vice-Minister of Agriculture and Commerce ... „
Snow, H. J. ..... *Yokohama.*
Sugi, K. ..... *Tokio.*
Talbot, W. H., Editor of the "Japan Gazette" ..... *Yokohama.*
Tappan, Prof. E. T. ..... *Gambier, Ohio, U. S. A.*
Toda, W. ..... *Tokio.*
Tomita, T. ..... „
Tuttle, Prof. A. H. ..... *Columbus, Ohio, U. S. A.*
Uriu, T. ..... *Handa Silver Mines, Fukushima Ken.*

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VAN BUREU, GEN. T. B., U. S. CONSUL GENERAL ..... *Yokohama.*
VAN DER POT, H.E. J. J., H. NETHERLANDS M. MINISTER RESIDENT „
WADA, T. ..... *Tokio,*
WADA, Y. ..... „
WAGENER, DR. G. ..... „
WOLFF, A., SWISS CONSUL-GENERAL..... *Yokohama.*
YAMAGAWA, PROF. K. .... *Tokio.*
YAMASHITA, D. ..... „
YATABE, M. ..... „
ZEDTWITZ, BARON F. VON, H. G. M. CHARGÉ D'AFFAIRES ..... „

Total, { Honorary Member, 1.
Corporation „ , 1.
Ordinary Members, 111. }

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